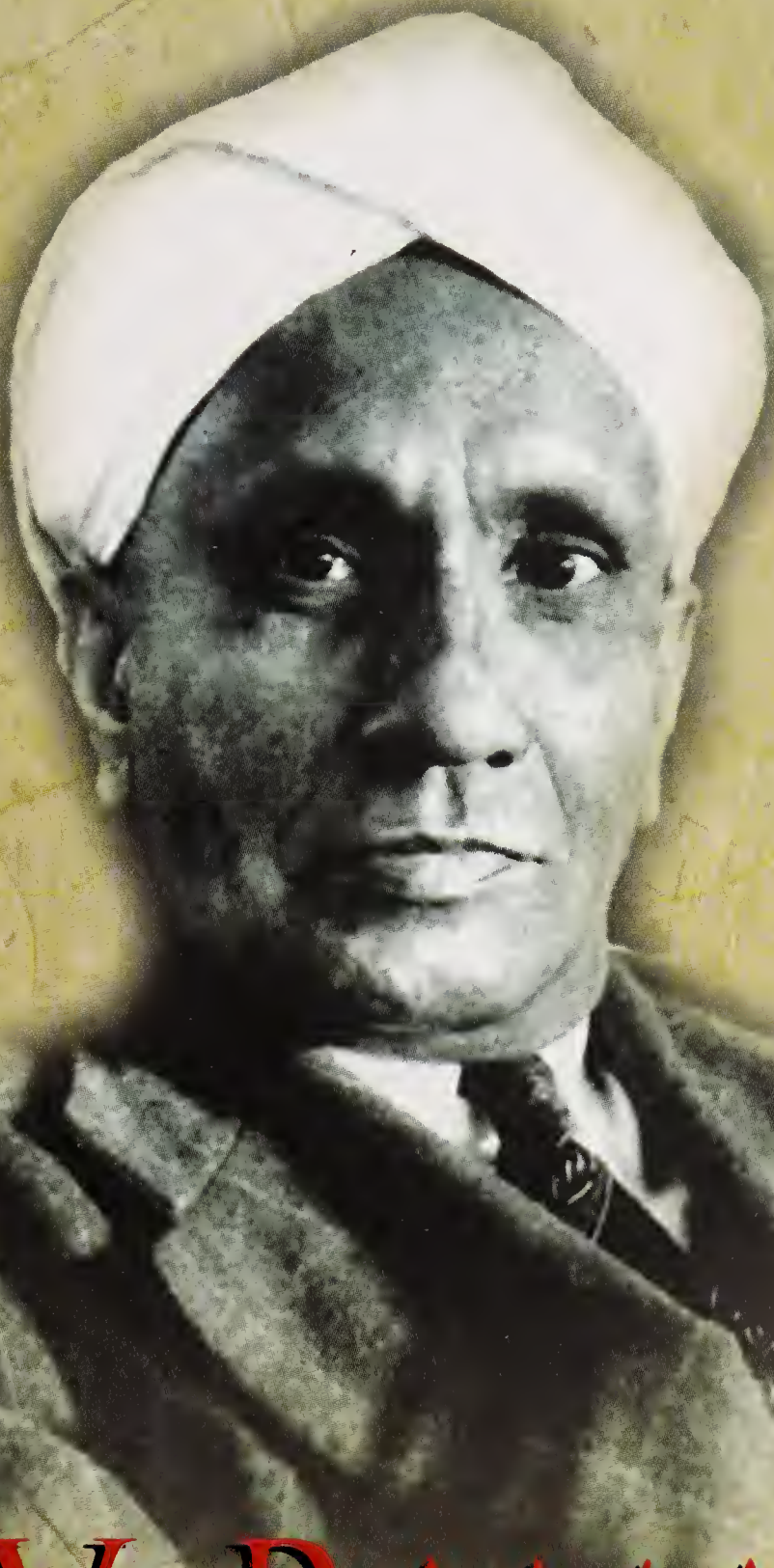

C.V. RAMAN

A MEMOIR

A. JAYARAMAN

About the Author

Dr A. Jayaraman was closely associated with Prof. C. V. Raman at the Raman Research Institute, Bangalore, for about 11 years since its inception, and was a collaborator of Raman in his research on the Physics of Gems and Minerals and Diamond. He left RRI on a post-doctoral fellowship to the Institute of Geophysics in UCLA in 1960 to work with Prof. George Kennedy, who initiated him into High-Pressure Research. In 1963 Dr Jayaraman joined the Bell Telephone Laboratories in the Physics Research Division, and retired in 1990. He spent a sabbatical year (1970) in Bangalore to set up facilities for High-Pressure Research in India for the first time, and then a 15-month term (1991-92) in the Physics Department at the Indian Institute of Science, to set up facilities to do High-Pressure Raman Spectroscopy work, using the Diamond Anvil Cell.

In June 1992, he joined the Hawaii Institute of Geophysics and Planetology of the University of Hawaii at Manoa, Honolulu, and held a Research Professorship for 5 years. Upon return from Hawaii he was associated with the Geophysical Lab of the Carnegie Institution of Washington in Washington, DC, for two years (1997 to 2000), before taking complete retirement from active scientific research. He now lives in Phoenix, Arizona, USA.

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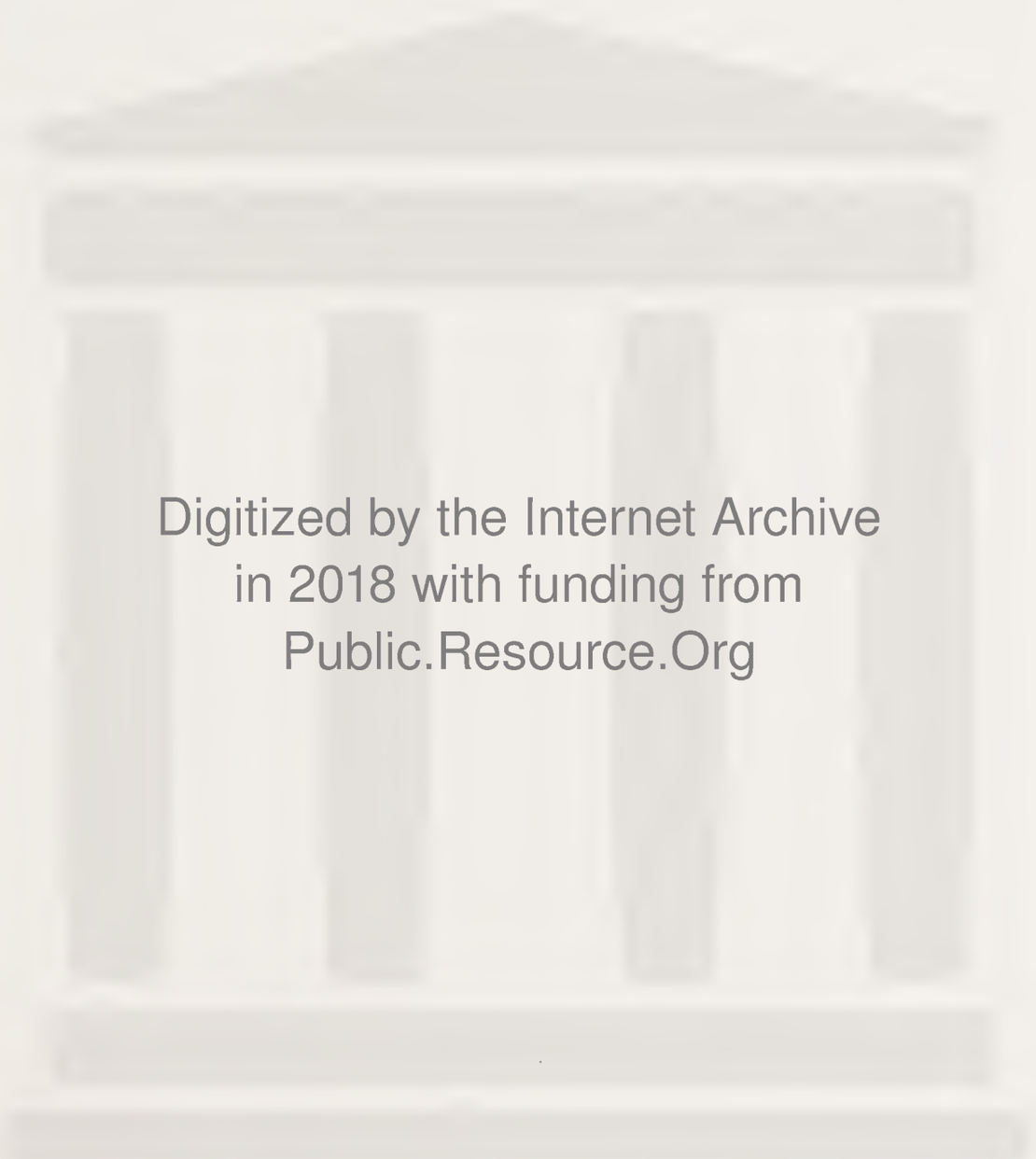
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CHANDRASEKHARA VENKATA RAMAN

— A MEMOIR

A line sketch of Raman by Homi Bhabha, 1949.

Chandrasekhara Venkata

RAMAN

A. Jayaraman

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Bengaluru 560 080

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Foreword

I am very happy that this book about Professor C. V. Raman, who founded the Indian Academy of Sciences in 1934, is being reprinted and republished by the Academy this year. The first edition of this book was published in 1988 by the Affiliated East-West Press and is now out of print. This edition has been entirely retyped and reformatted to take advantage of the changes in publishing methods in the past thirty years. I would like to record my sincere thanks to the President and the Staff of the Indian Academy of Sciences for taking a keen interest in reprinting this book. I am grateful to Mrs Dominique Radhakrishnan and the Raman Research Institute for permission to reproduce some of the new photographs that have been included in this edition, and to Dr Mohan Narayanan and Dr Vinodh Narayanan for their help.

The Indian Academy of Sciences is the right conduit to propagate the spirit in which this book has been written: I hope that it will impress upon young minds (in India and elsewhere) that great discoveries are the results of a keen observation of Nature and the persistent pursuit to find the truth. Raman used very simple equipment to make several significant discoveries using sunlight, including the Raman Effect itself. After the advent of lasers a Raman spectrum can be simply recorded in a matter of minutes, but it was a major challenge in Raman's time. During his Calcutta years he turned to sunlight to carry out the light scattering experiments which culminated in the discovery of the Raman effect. Using a set of complementary dye filters, he isolated narrow regions of the Sun's spectrum and visually

observed the very weak scattered light that had undergone a change in the frequency by interacting with molecules. Having seen with his own eyes that a very weak glow was separated by a dark band from the strong incident light, he employed a mercury arc lamp to confirm the nature of the very weak scattered light, namely that it consists of narrow lines, modified by the vibrating molecules. He has said many times that the cost of the equipment to make the discovery was a mere 500 Rupees of those times. I don't think many realize this – as well as the fact that it was scattered sunlight that gave him the first clue!

During the early years at the Raman Research Institute we did not have electricity for a long time – it took eighteen months to complete electrification after my joining, when I went to work with Raman. Undeterred by this disadvantage Raman asked me to direct a beam of sunlight reflected by a mirror from outside to do some beautiful work on optical phenomena exhibited by a class of mineral samples that he had collected for display in his Museum as well as for research. I did not realize at that time that the Raman effect was discovered using sunlight until one day he demonstrated it to me while we were doing other experiments.

Raman's was a very inspiring and colourful personality, and his contributions to science in India will last forever. I hope that this book captures these different aspects of Raman – the man and the scientist.

A. Jayaraman

Phoenix, February 2017

Foreword

The lives of men and women who achieve great distinction in science, literature or art hold a great fascination for the general public. A creative accomplishment standing well above even superior excellence is awe-inspiring. Even great discoverers reach the height of creativity only a few times during their career; the intense emotion then felt by them is best illustrated by the story of Archimedes running through the streets of Syracuse shouting "Eureka!".

The contemporary style of scientific reporting, as it has evolved, however, leaves out much of the drama — the initial inspiration, the feverish pursuit, the false trails and frustrations, and, finally, the ecstasy of discovery. Even the presentation of scientific controversies in the professional journals is subdued, thanks to alert editors! The excitement of scientific research, the colourful persons who populate the scientific community, the clash of personalities — all of these are carefully excluded from published literature, only to become a part of scientific folklore. Biographies of great personalities in science are, therefore, all the more precious documents. When written by their contemporaries, especially if by one of their close associates, they are invaluable.

Sir C. V. Raman, the discoverer of the Raman effect, made numerous innovative and original contributions to modern physics, optics and acoustics during the first half of this century. By his scientific accomplishments and by his unique scientific leadership in modern India, he made a profound impact. Dr A. Jayaraman, a condensed matter physicist internationally known for his pioneering

contributions to the physics of matter subjected to ultra-high pressures, was closely associated with Raman when he founded the Raman Research Institute in 1949 and developed it into a great centre of research.

For over eleven years, Jayaraman had the opportunity to interact with Raman on almost a daily basis and observe his scientific style, philosophy and motivations. We thus have here an authoritative biography of the most unique scientific personality of modern India, written with genuine understanding and admiration but with critical judgment and honesty which do not avoid the discussion of the all too human limitations of a great man. The result is an authentic narration from a person who knows his subject. Jayaraman has enriched the history of science by writing this biography.

A. K. Ramdas
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7 February 1989
West Lafayette, IN 47907
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Preface

Professor C. V. Raman was the most outstanding scientist that India gave the world. He not only became famous for his work but put India on the scientific map. He was a very colourful personality and a brilliant spokesman for science in India. Despite great disadvantages, namely the lack of a tradition for research in the country, the very little encouragement he received for pursuing a scientific career, and the meagre equipment available, Raman rose to the pinnacle of science and eminence. He gave up a lucrative Government job, to take up a Professorship that offered a fraction of the salary, only to advance his career as a scientist. His reward was the Nobel Prize for physics that was awarded to him in 1930 for his discovery of the light-scattering effect named after him.

He was a towering and dynamic scientific leader who inspired generations of students he trained in the methodology of research. He created the school of physics in Calcutta first, and then in Bangalore. His disciples came from all parts of India. He kindled their scientific interest and curiosity, and communicated to them the scientific spirit and the joy of scientific research. Many of his students and associates became in their lifetimes leaders of science and, in turn, created their own schools of research.

Raman was a brilliant and powerful speaker and his lectures, often with demonstrations, were a treat to listen to. A listener could never forget the exciting way in which he expounded a subject and the enthusiasm he generated. He wrote his scientific papers with meticulous care and often used Latin expressions to emphasise a

point. His flow and style of English were extraordinarily lucid; reading his scientific memoirs is like reading a piece of literary exposition.

He founded several scientific journals and nurtured them with care, for he believed that the quality of work and the quality of a journal go together. He published most of his scientific papers in these journals and encouraged his students and coworkers to do the same. He founded a Science Academy in Bangalore to serve as a forum for discussing scientific results and disseminating scientific knowledge through meetings, lectures and publications, by the Fellows of the Academy and their associates. He took a keen interest in the affairs of the Academy and got promising young scientists elected to the Fellowship of the Academy, long before they reached the peaks in their career. He could recognise talent and merit instinctively.

After his formal retirement from the Indian Institute of Science he founded the Raman Research Institute to pursue his scientific interests, for retirement from scientific work was inconceivable for Raman. The pursuit of Science was the most joyous experience for him; it was the breath of his life. His scientific interests spanned subjects ranging from physics to biology and he could be truly called a Natural Philosopher, a vanishing breed in these days of extreme specialisation.

Raman was fiercely independent in thought and action and fearless in expressing his views. He was respected and honoured by *Maharajas*, princes, politicians and the general public. The mention of the name Sir C. V. Raman evoked respect and admiration everywhere in India.

Raman had a finely honed aesthetic sense and loved Nature. He loved colour, wherever it was found, in trees, gardens, flowers, sunsets, mountains and lakes. He was very curious about Nature and natural phenomena. If a subject interested him, he went into it deeply without any preconceived ideas. He would question all previously held views and reject them if they proved contrary to his experience. He had the gift of being able to reduce complex problems to simple and fundamental propositions. He often used to remark that a

researcher should get to the wood and not be lost in the foliage. Raman was an experimentalist *par excellence*. In the understanding of physical phenomena, his physical intuition often leaped several steps over mathematics.

Raman was kind and generous to his associates and students. He was quick to express appreciation of good work and also to give tremendous encouragement at the right time. But he was also a man of strong emotions and could get violently angry, when provoked. In life he had fought many battles, both scientific and nonscientific. He had to face very difficult situations, but he never gave up hope, rejuvenating himself by immersion in scientific work.

What motivated Raman to do the extraordinary things he did against all odds? What was the secret of his success? These are questions to which there can be no simple answers. In fact, there will be as many answers as there are minds that ponder over such questions. But the events and course of his life are there, as facts, to examine, to marvel at, and, perhaps, to provide a glimpse of understanding.

I had the greatest good fortune to be associated with him for eleven years, from 1949 to 1960, and moved closely with him, on a day to day basis. He was very kind and generous to me and trusted me very much. In fact, he treated me like his son, sharing his views, his ideas and his dreams. For me, this was a period of great education and experience and I owe my whole scientific career to him.

There are only a few biographical sketches on Raman — very few in fact — including a recent one by G. Venkataraman. I thought a first-hand account of Raman and his life would be of interest to and, perhaps, inspire some young aspirants to a career in Science. My account is, therefore, highly personalised, contains a lot of anecdotes and has been written with a lay reader (with some interest in Science) in mind. I have tried to cover the entire life of Raman to make this memoir complete. But because of my association with Raman in the later period, it may seem that I have devoted more pages to this period. My justification is that you get a more complete view of a person only from the vantage point of proximity. I, however, did not keep any diary and, hence, most of this account is from memory.

In writing this memoir, I have used material from the following: (1) An extraordinarily interesting and lucid account of Raman by the late Dr L. A. Ramdas in two articles published in the *Indian Journal of Physics Education* in 1971; (2) A concise but authentic and accurate biographical sketch of Raman by Prof. S. Bhagavantam, published by the Andhra Pradesh Academy of Sciences, Hyderabad; (3) Extracts from the Indian Academy of Sciences' publication in 1984 entitled *The First Fifty Years*; (4) Extracts from Prof. S. Ramaseshan's articles and lecture, 'C. V. Raman Memorial Lecture' given at the Indian Institute of Science, Bangalore, and from *C.V. Raman and the German Connection*, an article written on the occasion of the Silver Jubilee of the Max Mueller Bhavan; (5) Extracts from the *Calcutta Municipal Gazette* dated July 4, 1931; (6) Extracts from the article on Sommerfeld's meeting with Raman in Calcutta in 1928, published by Dr G. Torkar in the *Journal of Raman Spectroscopy*, 1986; (7) Extracts from the article *Golden Jubilee of the Discovery of the Raman Effect*, February 28, 1978, by the late Prof. K. R. Ramanathan published by the Andhra Pradesh Academy of Sciences, Hyderabad; (8) Extracts from *Bhavan's Journal*, December 1970; (9) Extracts from the *Pasadena Star*, very kindly supplied by Paula Agranat Hurwitz of the California Institute of Technology Archives, Robert A. Millikan Memorial Library; and (10) Prof. B. S. Ramakrishna's articles on Indian Musical Drums and on Raman in *Science Today*, 1970. All these sources have been invaluable to me and I wish to record my deep sense of gratitude to the authors of these articles and their publishers. My grateful thanks are also due to Professor S. Chandrasekhar for permission to quote some of his statements.

I am very indebted to Prof. A. K. Ramdas in many ways. He patiently read the manuscript and made illuminating comments and suggestions. He agreed to write a foreword and made available to me much interesting material concerning Raman from his father's writings and collection.

My associate Ralph G. Maines has been extremely helpful in the course of the preparation of the manuscript and I wish to record my

thanks to him. I am very indebted to Mrs Alyne E. Bonnell in our text processing centre, for the enthusiasm and readiness with which she did the typing and the keen interest she took in the work. My wife Kamala has been a constant source of encouragement to me throughout my scientific life. She read the manuscript of this memoir and made interesting comments from the point of view of a non-scientific reader, for which I wish to record my sincere thanks to her. This work would not have been possible without the support and encouragement of AT&T Bell Laboratories, my employer for the last quarter century.

A. Jayaraman

18 May 1989
AT&T Bell Laboratories
Murray Hill, NJ-07974
USA

Chapter I

Prelude

Chandrasekhara Venkata Raman (C. V. Raman) startled the scientific world in 1928 when he announced his discovery of the light scattering effect named after him. The discovery was the culmination of seven years of dedicated work on the subject of light scattering by Raman and his band of devoted students and co-workers.

Very soon after the discovery, R. W. Wood, then Professor of Physics at Johns Hopkins University in Baltimore, USA, sent a cable to *Nature* which read: "Professor Raman's brilliant and surprising discovery that transparent substances illuminated by very intense monochromatic light scatter radiations of modified wavelength and that frequency difference between the emitted radiation and the one exciting the medium is identical with the frequency of the infra-red absorption bands, opens up a wholly new field of study of molecular structure. I have verified this discovery in every particular... It appears to me that this very beautiful discovery, which resulted from Prof. Raman's long and patient study of the phenomenon of light scattering, is one of the most convincing proofs of the quantum theory of light which we have at the present time."

It is of particular significance that the equipment which Raman employed for the discovery were very simple and cost only Rs. 500 at the time. Very few scientists have made such a profound discovery with such simple equipment.

In 1931, C. J. Davisson, who shared the 1937 Nobel Prize for physics with G. P. Thomson, commenting on 'Sir Chandrasekhara Venkata Raman, Nobel Laureate' in the April 1931 issue of *Bell Laboratories Record*, had this to say: "It was remarked earlier on that the Raman experiment is a rather simple one which might have been made with equipment available in any physical laboratory at any time in recent decades. It was no accident, however, that this particular discovery was made by Raman rather than someone else. Important discoveries in physics, even quite simple ones, are usually made only by investigators who have cultivated intensively the particular field concerned, and this is strikingly true in the present instance."

In the same article, Davisson comments: "It speaks well for the development of science in India that Professor Raman apparently owes little or nothing of his eminence to direct contact with physicists in other countries. His formal training was received entirely in India, and, except for a single year, he has worked only in his native land. In 1924 he attended the Toronto meeting of the British Association and afterward carried on his researches for some months at the California Institute of Technology."

Raman was a native genius who put India on the scientific map by his own efforts. For almost six decades, Raman's personality made its deep impression on the Indian scientific scene. The story of his success has few parallels, at least in the Indian context. His achievement can only be attributed to the singular nature of his personality, and the energy and vigour with which he pursued his goals. Max Born has said of Raman: "There is no Indian physicist of the rank of Raman. No man can compare with regard to his vigour or intensity. This European intensity which Raman exhibits to a marked degree would make an average Indian scientist suspicious of him."

Raman showed an uncommon ability for independent thinking right from the beginning. When he took to scientific research, he was supremely confident of outstanding achievement. He used to remark that he would bring the Nobel Prize for physics east of Suez. Rabindranath Tagore had won a Nobel Prize for literature in 1913,

but Raman was the first Asian to win the Nobel Prize in a scientific field. Viewed from the times in which he was born and raised, it was a statement no one lesser than Raman in determination could have made.

Raman was born on November 7, 1888, in South India and died on November 21, 1970. He was active as a scientist almost to the very end. 1988 marked both the birth centenary of Raman as well as the diamond jubilee of the Raman Effect.

The scientific climate in India and British rule

India is a land of ancient civilisation and, through the ages, has produced great savants, scholars and religious preceptors. Ancient India's contributions to medicine and mathematics have been significant and well documented. However, modern Science, which overtook Europe during the age of Renaissance, did not come to India until much later. This was partly due to its religious attitude and partly due to its political history.

The British introduced modern education in India around the middle of the 19th century. Three universities were set up in Calcutta, Madras and Bombay in 1857 patterned after the London University. By the end of the 19th century there were about 200 colleges. Most Indians who received modern education in these universities and colleges sought government jobs. The best of the crop went into the Indian Civil Service and the Financial Civil Service, the two most prestigious services under British rule. Only a few took to Science, for the pursuit of Science offered very little scope for advancement to the young and the talented.

A small number of individuals who took to Science went to Europe for higher studies and research and returned to India with doctorate degrees, before pursuing scientific and teaching careers. This trickle produced some outstanding scientists and by the dawn of the 20th century, there were, at least in Bengal, one or two scientific societies and a few well known Indian scientists. The names of Sir J. C. Bose, the physicist-cum-botanist, and Sir P. C. Ray, the chemist, were well known. Thus, Science in India at the time was

largely the effort of a few individuals; there were no great laboratories, except a few fledgling scientific institutions. However, the early pioneers gave a valuable start and the English professors teaching in the colleges seem to have, by and large, encouraged the brighter students. It was in this scientific milieu that Raman blossomed.

Family and education

Raman was born the second child in a family of eight children, in a village near Trichinopoly in South India, where his father, Chandrasekhara Iyer, was a teacher in a local high school. Chandrasekhara Iyer was the first person in the family to receive an 'English' education, getting his B.A. degree in Trichinopoly, while working as a teacher.

The family had only modest means, but this did not stop the progressive Chandrasekhara Iyer from giving his sons an 'English' education. Iyer also seems to have had artistic inclinations, for he learned the violin and apparently played it exceedingly well. This is significant because, later, Raman, during his scientific career, studied the physics of the violin. Raman's elder brother, Subrahmanya Ayyar, was also an expert musicologist who had mastered the violin. Not much information is available on Raman's mother, Parvathi Ammal, except that she was a gentle and tolerant lady, firmly rooted in the home and family life. When a correspondent asked Raman much later in life if he came from a wealthy background, Raman seems to have heartily laughed and replied: "I was born with a copper spoon in my mouth. At my birth my father was earning the magnificent salary of ten rupees per month!"

When Raman was four years old (1892), his father accepted a post of lecturer in mathematics and physics in the coastal town of Visakhapatnam in what is now Andhra Pradesh and moved there. Raman spent the next ten years of his life in Visakhapatnam, going through primary and secondary schools and two years of college. In January 1903 he won a scholarship and joined Presidency College in Madras for his undergraduate studies. This institution had

been set up by the British Government to provide higher and quality education for aspiring students in South India. In those days, it was staffed mainly by English professors. The college had also acquired a great reputation at that time because of the illustrious men it had produced. Its alumni rose to high ranks in Government Service, or became judges and lawyers. It also produced outstanding scientists, of whom C. V. Raman and S. Chandrasekhar became recipients of Nobel Prizes for Physics. Unfortunately, after India's independence, Presidency College is no more the citadel of higher education in South India it once was.

Raman entered the portals of Presidency College as a young lad of 14 and when he went into his English class for the first time he apparently created a mild sensation. The English Professor turned to him and asked if he belonged to the B.A. class, to which Raman replied, "Yes, Sir". Referring to this incident, Raman later wrote:

> "Some of my pleasantest recollections of the four years I spent at the Presidency College in Madras are of extraordinary kindness and consideration which I received from the European members of staff. Their attitude seems all the more surprising when I look at the undistinguished and diminutive figure of myself thirty-five years ago, as it appears in the college photographs of those days. Wearing a linen cloth in the cylindrical style of boyhood and a home-knitted cap of wool of no particular shape, I could readily have been mistaken for a high school lad who had by accident got mixed up with a college crowd. Indeed, in the first English class I attended, Professor E.H. Elliot addressing me asked if I really belonged to the junior B.A. class, and I had to answer in the affirmative. He then proceeded to inquire how old I was."

Raman passed the B.A. degree examination in 1904, at the age of 15, winning first place and gold medals in English and Physics.

Although Raman possessed a superior intellectual and mental capacity, his health was not equal to them. He appeared physically frail and was considered rather a weakling. When he passed his B.A. examination, his teachers suggested that he should go to England

for higher studies. However, the Civil Surgeon of Madras, to whom he was sent for a medical check, declared that Raman was unfit to withstand the rigours of the English climate. Therefore, all ideas of sending him abroad had to be abandoned. Much later Raman appears to have said, "I shall ever be grateful to this man". In retrospect, what happened to Raman was a great blessing in disguise. It enabled him to chalk out his own path for a future in research. He went ahead and took his M.A. degree in 1907 at the age of 18, again topping the class with record marks.

It is said that when he was in middle school he used to read books on Science at a level far in advance of his age and expectation, and performed experiments with improvised apparatus at home and in school. This absorption and fascination for physics were noted by his mentors in Presidency College and his professors exempted him from attending all Science classes, as they felt that he had nothing new to learn from their lectures. Some of the certificates that his teachers gave speak for Raman's interest in English literature and for the independence and strength of character he possessed even as a young student: "The best student I have had in thirty years"; "Has an unusual appreciation for English literature"; "Possesses a remarkable facility for idiomatic expression"; "Possessing great alertness of mind and strong intellectual grasp".

Research in the modern sciences was quite unknown in India in those days, but young Raman, at the age of 16 and while still a student in the M.A. class, published a paper in that prestigious journal, the *Philosophical Magazine* (London), in November 1906, entitled *Unsymmetrical diffraction bands due to a rectangular aperture observed when light is reflected very obliquely at the face of a prism.* This was evidently a routine class experiment in optics during which Raman discovered these bands. This observation formed the first research publication of Raman and was followed by a note in the same journal on a new experimental method for measuring surface tension. These papers were communicated by the author himself and contain no acknowledgement of help received from anyone, indicating that they were based on totally independent work by Raman.

It is important to note that Presidency College was primarily a teaching institution at that time and had no tradition at all for research. It was therefore unusual for a young student to produce research publications and have the courage to publish them promptly in the most prestigious journal at that time. It was clear even from the beginning that Raman was cut out for independent thinking. Further, his urge to put experimental observations in print as expeditiously as possible was a trait which was crucial to his career as a physicist. Indeed, this helped him to establish his priority in the biggest discovery he was to make much later in his career.

Even as a student he was apparently familiar with Lord Rayleigh's scientific papers and his treatise on sound as well as with the works of Helmholtz. Much later in life Raman spoke of Helmholtz thus:

> "Speaking of the modern world the supremest [sic] figure, in my judgement, is that of Hermann von Helmholtz. In the range and the depth of his knowledge, in the clearness and the profundity of his scientific vision, he easily transcended all other names I could mention, even including Isaac Newton. Rightly he has been described as the intellectual colossus of the nineteenth century. It was my great good fortune, while still a student at college, to have possessed a copy of an English translation of his great work *The Sensations of Tone*. As is well known, this was one of Helmholtz's masterpieces. It treats the subject of music and musical instruments not only with profound knowledge and insight, but also with extreme clarity of language and expression. I discovered the book myself and read it with the keenest interest and attention. It can be said without exaggeration that it profoundly influenced my intellectual outlook. For the first time I understood, from its perusal, what scientific research really meant, and how it could be undertaken. I also gathered from it a variety of problems which were later to occupy my attention and keep me busy for many years."

Entry into the Financial Civil Service

In those days the highest career open to bright students was entry into the Indian Civil Service. Since entry into the ICS. involved some degree of training in England, this was ruled out for Raman, but he was encouraged to appear for the Financial Civil Service. Raman appeared for the competitive examination for the FCS. held in February 1907. He secured the first place and was selected. His elder brother, C. Subrahmanya Ayyar, had already entered this service.

Just before this turn of events and immediately after graduating from the M.A. class, Raman married Lokasundari, daughter of S. Krishnaswami Iyer, who held the post of Superintendent of Sea Customs at Madras. There was a slight hitch with regard to this marriage, for Raman and Lokasundari Ammal belonged to two different subcastes. In those days, marrying out of the subcaste was tantamount to a serious transgression of the social code. The father of the girl was apparently not a willing party to the alliance, but the mother, Rukmani Ammal, found young Raman quite acceptable.

The story goes that on the first occasion Raman saw Lokasundari, she was playing on the veena the famous Tyagaraja composition, *Rama ni samanam evaro*, which means 'Who is equal to you, Rama?'. Lokasundari must have hit the right chords not only on the veena but in her future husband to be, for Raman firmly resolved to take her as his partner after the meeting. Referring to this incident later, Lady Raman would often say that she did not know if Raman fell for her and the music, or for the extra allowance of Rs. 150 which the Finance Department gave its married officers. The wedding took place in Madras in 1907.

Raman, along with his wife, arrived in Calcutta later in 1907 to join the Finance Department as an Assistant Accountant General. He was only 18½ years old. The Ramans rented a house in Scot's Lane, off Bowbazar Street, and it looked as if the die was cast, that Raman would have a long career in the Finance Department of the Government of India and progress up the ladder with the years. But

Raman's real interest was rooted in physics and an inner urge drove him to seek an opportunity to satisfy this inner calling. He then discovered the Indian Association for the Cultivation of Science located at 210 Bowbazar Street, only a few blocks away from where he lived.

The Indian Association for the Cultivation of Science

The Indian Association for the Cultivation of Science had been in existence since 1876, founded by a leading medical practitioner in Calcutta, one Dr Mahendra Lal Sircar. He had an abiding interest in Science and foresaw the great role Science was destined to play in India. He wanted to create an Association combining the features of the Royal Institution of London and the British Association and had devoted a good part of his life to collecting funds from several princes and prominent citizens for founding the Association of his dream, where young aspirants could devote their lives to the pursuit of science. The Association building had several large halls for laboratory purposes and an excellent lecture theatre that could accommodate a large audience. During the lifetime of Mahendra Lal Sircar, he organised lecture courses for students, himself lecturing and getting others to give popular Science lectures. However, the dream of a research institution remained unfulfilled during Mahendra Lal Sircar's time.

In those times, scientific research in India was non-existent and the institution decayed in 25 years, to dusty rooms and unused laboratories. In desperation, Mahendra Lal Sircar seems to have declared: "I don't know how to account for the apathy of our people towards the cultivation of Science. Younger men must come and step into my place and make this a great institution." That prophetic wish was to be fulfilled by Raman.

Mahendra Lal Sircar died in 1904 rather a disappointed man. His son, Dr Amrit Lal Sircar, succeeded him as the Honorary Secretary of the Association and was guiding the affairs of the Association at the time Raman's attention was drawn to it. Soon after his arrival in Calcutta, Raman one day noticed the Association's signboard while returning home from work in a tram car. He immediately

alighted from the car and knocked on the doors of the Association, full of excitement and enthusiasm. Admitted inside by a person called Asutosh Dey, who was later to become Raman's most devoted assistant, Raman met Amrit Lal Sircar and asked him if he could conduct research at the Association during his spare time. The story goes that Amrit Lal Sircar embraced Raman, exclaiming that they had been waiting for a person like him all these years, and how happy his father would have been to witness the entry of such a person into the Association.

The Association premises consisted of a dusty lecture hall and a large laboratory with dustier equipment, most of it meant for demonstration. However, Raman set to work with enthusiasm and very soon started producing research papers. From 1907 to 1917, except for short absences from Calcutta on transfer to Rangoon and Nagpur, Raman spent all his leisure time, which meant the evenings and very late into the night daily, conducting experiments at the Association. At that time, Raman's research was directed to the acoustics of Indian musical instruments and he published his findings in foreign journals as well as in the *Proceedings* and bulletins of the Association.

All the facilities of the Association were at his disposal and he also had the devoted and loyal assistance of Asutosh Dey, known to everyone in the Association as Ashu Babu. Raman soon turned the Association into a beehive of activity. His devotion and dedication to research attracted many young students, teachers and professors from local colleges and the universities, who joined him to participate in the scientific excitement he generated.

All this meant a different story for Lokasundari Raman, a young bride thrust into the hands of a strange young man with a consuming passion for science. Lokasundari Raman once described the routine of Raman thus: At 5.30 a.m. Raman goes to the Association, returns at 9.45 a.m., bathes, gulps his food in haste, leaves for his office, invariably by taxi to be on time for work; at 5 p.m. he goes directly to the Association on his way back from office and comes home at 9.30 or 10 p.m., after spending the evening at the laboratories of

the Association; Sundays are spent entirely at the Association. How could a wife tolerate such a situation!

It is remarkable that Lokasundari Raman went along with Raman in this quest for scientific knowledge. She stood by him devotedly throughout his life and endeared herself to all who associated themselves with her husband. She once related, with a smile, how difficult it was to turn Raman's attention from scientific pursuits to the obligations of matrimony. Two sons were born to the Ramans — Chandrasekhar in 1921 and Radhakrishnan in 1929 — and that, Lokasundari declared, was a miracle, for Science was his first love.

Palit Professor

Raman made such a profound impression on the leading educationists and citizens of Calcutta that Sir Asutosh Mookerjee, the Vice-Chancellor of the Calcutta University, offered him the Sir Tarakanath Palit Professorship of Physics at the University College of Science, Calcutta. The appointment to the chair, however, required that the candidate should have received training abroad. Raman refused to comply with this condition. The Vice-Chancellor eventually changed the provisions and Raman took the chair in 1917. His resignation from the FCS meant giving up a lucrative job in exchange for one with five times less emoluments.

When announcing his plans for filling the chair, Asutosh Mookerjee stated:

> "For the chair of Physics created by Sir Tarakanath Palit, we have been fortunate enough to secure the services of Mr Chandrasekhara Venkata Raman, who has greatly distinguished himself and acquired a European fame by his brilliant researches in the domain of Physical Science, assiduously carried on under the most adverse circumstances and amidst the distraction of pressing official duties.
>
> "I shall fail in my duty if I were to restrain myself in my expression of the genuine admiration I feel for the courage and spirit of self-sacrifice with which Mr Raman has decided to exchange a lucrative official appointment for a University Professorship, which,

I regret to say, does not carry even liberal emoluments. This one instance encourages me to entertain the hope that there will be no lack of seekers after truth in the Temple of Knowledge which it is our ambition to erect."

The encomiums paid to Raman on this occasion were well deserved. The remarks made by Asutosh Mookerjee, as well as the manner in which Raman made his decision, have a deeper significance than what is apparent, in the context of the situation in the country at the time. Scientific research as a whole-time career was not heard of in those days in India and most of the top students of the time, like Raman, drifted from college into Government Service almost as a matter of routine. However, the fact that Raman showed scant regard for material prospects and did not hesitate to exchange the position he was enjoying with an academic appointment, at the first available opportunity, is unique. This decision of his was one of considerable significance. Very few persons would have had the courage to do so.

The surrender of what might be called the preferments of office in favour of the pursuit of knowledge, especially when a person is well settled in life, as Raman was at that time, is certainly an act of great courage. But it is interesting to note that Raman is reported to have remarked on one occasion, in a mood of introspection, that Sir Asutosh's offer of the professorship to an unknown government official was an act of great courage, whereas his own acceptance of it without demur was just a case of following his inclinations. Events that followed have more than justified the hopes entertained by Asutosh Mookerjee in offering the professorship to Raman and the ambitions that impelled the latter to accept it.

Prof. Raman's residence at Calcutta used to be just behind the Association. He had, therefore, provided himself a back door entrance by which he could enter the Association at any time of the day or night, for he never worked according to the clock. Asutosh Dey (Ashu Babu), the Assistant Secretary, resided on the premises and was ever ready to assist Raman whenever he wished to carry out his experiments at the Association's laboratories. Raman often used to work far into the night and, when exhausted, sleep on a table until the

astonished Ashu Babu awakened him next morning! On most mornings he would come in informal dress to the Association and carry on experiments until 9.30 a.m., when he would remember his lecture engagement at the University College of Science four miles away. A quick return home, a few strategic sweeps of his razor, a quick bath, a hurried dressing up that included arranging the inevitable Madras turban, and he would shout at the top of his powerful voice, "Ashu Babu — taxi", evoking an equally loud response from Ashu Babu! Snatching his breakfast on the run, he would rush into the Association with a sheaf of his lecture notes for the day, jump into the waiting taxi with his laboratory attendant Shivnandan and, after a hectic drive, reach the Science College just in time to start his lecture. Such was the course and tempo of his life throughout practically his whole stay in Calcutta.

This was the time of the non-violent, non-cooperation movement. Sometimes bands of students, who had given up their studies at the call of Mahatma Gandhi, used to squat in front of the Science College in Upper Circular Road, barring entry to professors and students alike. On most of such occasions, by cajolement, entreaty or otherwise, 'Raman Saheb', as he used to be affectionately called in those days, would break the cordon and rush into the classroom. Calcutta was a most exciting city in those days, but the watchword of the demonstrators used to be 'non-violence' at any cost!

The laboratories of the physics department of the College of Science, particularly the many large halls reserved for the M.Sc. scholars for their practicals, had, in 1920, a rather empty look. The equipment for many important experiments to be performed by the students had to be improvised. The students had ample scope for rigging up many of the gadgets needed for the prescribed experiments. This atmosphere of improvisation was indeed very stimulating, as it made demands for considerable skill on the part of the scholars as well as their guides. The experiments so set up by one batch of students were available to the next years' batch and so on, so that in a few years' time the laboratories were more or less filled with all the essential experimental arrangements for the M.Sc. courses in

the various branches of Physics. These were later supplemented by standard equipment ordered from abroad.

First trip abroad and entry into light scattering

Raman's first trip abroad was to the UK, to attend the Congress of Universities of the British Empire held in the summer of 1921 at Oxford. He represented the University of Calcutta at the Congress. This visit gave him an excellent opportunity to meet the leading scientists of the British Empire, who knew about Raman and admired his researches at Calcutta. His lecture at the Physical Society of London on his latest researches in Optics and Acoustics, with experimental demonstrations, drew a large number of physicists and was immensely appreciated.

About this time, Raman was getting deeply interested in Modern Physics. Before long, in fact during the return voyage, he laid the foundations for what were to be some of his most outstanding researches for the next few decades. An intense love of Nature, of the beauty of natural phenomena and of colour in scenery was one of the most prominent traits of Raman. Now, during this voyage, he became fascinated with the deep blue colour of the sea.

The late Lord Rayleigh had some years earlier explained another natural phenomenon, *viz.* that the blue of the sky was due to the scattering of sunlight by the molecules constituting the atmosphere. Such an authority like Lord Rayleigh also arrived at the questionable conclusion that the blue of the sea was due to the reflection of the sky blue by the ocean's surface!

Raman's marvellous intuition led him to examine the colour of the ocean very critically during the voyage. He used the simplest of equipment, *viz.* just a Nicol prism, to help him. His wonderful imagination now led him to eliminate the sky-light reflected by the sea surface at the Brewsterian angle by observing the sea surface in the crossed position of the Nicol prism. He was dismayed to find the colour of the sea persisting as a much richer blue than that of the sky!

Even on those occasions when the sea was disturbed by waves, he found that the deep blue of the sea itself came out unmistakably,

on quenching with the crossed Nicol prism the polarised light of the sky reflected by one side of the waves. By the time he got back to Calcutta, he was quite convinced that the blue colour of the sea was due to the scattering of the incident sunlight by the molecules of liquid water and that Lord Rayleigh's earlier suggestion was not altogether correct.

Immediately after arriving in Calcutta, Raman started critical laboratory experiments with samples of water kept in clean rectangular glass vessels and illuminated laterally with a strong parallel beam of light. He observed the track of the beam in a perpendicular direction. During the next three or four weeks he carried out several crucial experiments with water. The disturbing effect of dust was eliminated by using distilled water kept at rest for many weeks, thus allowing most of the motes time to settle down. The lateral scattering now came out as a feeble blue track that was very highly polarised. The intensity of scattering by water, as observed and as calculated from the Einstein–Smoluchowski formula (originally worked out to explain the very strong critical opalescence of liquids at their critical temperature), was shown to be just 160 times stronger than in pure dust-free air.

Raman wrote his classic paper *The Molecular Scattering of Light in Water and the Colour of the Sea* within a month of his return to India and it was published in the *Proceedings of the Royal Society of London* (Vol. A. 101, 1921, pp. 64–80). Only after sending away this paper for publication did he travel down to South India to meet his wife.

Soon after his return from South India, Raman started writing out his memoir entitled *The Molecular Diffraction of Light.* In its chapters, besides discussing results already obtained, he outlined plans for the many further experimental researches to be undertaken urgently to investigate the molecular diffraction of light by matter in the gaseous, liquid and solid states, during its transitions from the gaseous to the liquid and from the liquid to the solid states, in liquid mixtures, in solutions and in relation to chemical constitution. In this

remarkable and prophetic memoir, Raman even discussed the possible implications of the quantum theory in one chapter. This memoir was published by the Calcutta University Press in February 1922, indeed as expeditiously as it was written by the author.

This is the only book Raman wrote until he published his *Physiology of Vision* in the Sixties. To the question why he had not written books, he would reply: "When I start to write something, I get so many new ideas it becomes impossible to proceed further. Then I go to the laboratory to work on the new ideas." From 1921 onwards, the subject of light scattering became the main theme of the Calcutta group led by Raman, which culminated in the discovery of the Raman Effect.

By 1924, Raman's outstanding researches had won for him worldwide recognition and the Royal Society of London conferred on him the high distinction of 'Fellow of the Royal Society: (F.R.S.)', at the young age of 36. This was universally hailed with enthusiasm in India as recognition of native scientific endeavour.

Visit to Pasadena

Very soon after he became FRS, Raman was invited by the British Association for the Advancement of Science to inaugurate the discussion on *The Scattering of Light* at its session in Toronto in Canada in June 1924. After opening the discussion at Toronto, he travelled with the Association across Canada, and then visited Toronto again to attend the International Congress of Mathematicians, as a representative of the Calcutta University. He then proceeded to Philadelphia, USA, to attend the Centenary of the famous Franklin Institute. Also attending this Centenary was the leading American physicist, R. A. Millikan, who invited Raman to spend some months as Visiting Professor at the California Institute of Technology, Pasadena. During the fall and winter of 1924, Raman delivered a regular course of lectures on thermodynamics to a group of American physicists and senior scholars at the Norman Bridge Laboratory of Physics, Pasadena.

R. A. Millikan and C. V. Raman, Bangalore 1940. (Photo courtesy of California Institute of Technology Archives, Pasadena, California)

Commenting on two special lectures delivered by Raman before an enthusiastic audience at the California Institute of Technology, the local newspaper, *Pasadena Star News,* referred to them as particularly fine speeches, understandable even to nonspecialists. It complimented Raman on his ability to expound on a subject with clarity and eloquence combined with a rare sense of humour.

The speech given at the monthly dinner of the University Club on the evening of November 18, 1924, was reported by the paper in its November 19, 1924, issue under the heading 'Famed Indian Scholar is Speaker'. *A Game of Chance* was Raman's subject. The paper stated: "As Professor of Thermodynamics in the University of Calcutta, India, Dr Raman is known as one of the foremost authorities on natural science in Asia. He is in Pasadena as a special lecturer on physics at California Institute of Technology."

Introducing Dr Raman, Clinton K. Judy, President of the University Club, emphasised the privilege enjoyed by the organisation in listening to a scientific scholar from the Orient. "Most Hindus coming to this country talk on philosophy and the occult, and it is a distinct novelty to have one who is more in accord with Western scholarship" said Professor Judy.

Dr Raman proved himself an entertaining speaker, displaying a delightful strain of humour. He began by stating that games of chance had always held a deep fascination for the human mind. In support of this, he recalled several legends from the ancient Sanskrit, according to which humans played at dice with the Gods.

Drawing interesting analogies between games of chance and the issues of life, Dr Raman said there really was no such thing as chance, because everything happened for definite reasons. But those for which the causes were not known were characterised as chance.

In the course of his remarks, Dr Raman described some of the experiments that famous mathematicians had conducted to work out the details of the law of probabilities, recalling battles that many University Club members themselves had fought with sequences, choice and chance in their college days. Fascinating, too, were his remarks on the law of irreversibility, something which, he said, few people ever thought about.

It was an evening of mental gymnastics, which Dr Raman concluded by saying, "The greatest game of chance of all is Nature" — thus adding a touch of the mystical and giving the audience something more to think about.

The *Pasadena Star News* dated December 19, 1924, reported another lecture by Raman under the heading: 'Fine Lecture Offered By Indian, Prof. C. V. Raman of India Speaks on Light Theories, Demonstrates Talk With Many Experiments of Keen Interest'. It then went on to say:

> "Prof. C.V. Raman, noted Indian scientist, and professor of physics at the University of Calcutta, India, yesterday addressed an enthusiastic audience of more than 300 teachers, students and graduates of the

California Institute of Technology on the subject of *The Scattering of Light and Its Relation to Atomic and Molecular Structure.*

The noted scientist, who has come to the Southland from Toronto, Canada, where he recently arrived from India, received a splendid tribute from his interested audience at the close of his address.

Both the physicist and the chemist, Dr Raman believes, have left a neutral space between their theories as to the construction of the atom, especially as those theories apply to light, and his mission was to give each food for thought, so that the two great sciences might be brought closer together.

Dr Raman first developed the theory of the 'scattering' of light on a trip in the Mediterranean Sea. The deep blue of that great body of water was a puzzle to him, and he finally solved the mystery, at least to his own satisfaction, by proving with hundreds of experiments, that the scattering of sunlight itself was responsible.

His lecture was illustrated with many experiments, given in such a simple and direct manner that they could be easily understood by a less scientific audience than that present.

One piece of apparatus which he has invented for the study of light-scattering in gases and vapour, is a huge black box, seven feet in height, in which an observer may station himself, and in which an apparatus contains the gas, air, or vapour, to be studied. Dr Raman, with rare humor has named this 'The Black Hole of Calcutta'.

In one demonstration, the scientist gave a remarkable view of the setting sun, which he obtained by using a liquid encased in a square glass receptacle in the receptor of a projector, instead of a slide.

Dr Raman is a graduate of the University of Madras in Southern India, and is among the most noted teachers in the world of science. This is his first visit to the United States and to California and he was enthusiastic about the Southland. Interest in his subject here surprised him; attendance at scientific lectures in India he said being one of the much desired conditions that is sadly lacking."

Raman's visit to Pasadena enabled him to develop a lifelong friendship with Millikan and other leading American physicists. The admiration of Millikan for Raman is reflected in the announcement of a lecture at California Institute of Technology. This announcement, dated December 9, 1924, was evidently prepared by Millikan himself.

> "The Friday Evening Demonstration Lecture this week at the California Institute of Technology will be one of unusual interest, both because of the personality of the speaker, and because of his subject. Dr C. V. Raman, Professor of Physics at the University of Calcutta, India, will be the speaker and his subject is *The Study of Musical Instruments*.
>
> Dr Raman stands out as one of the most productive scientists of the Orient. He has already done a surprising amount of high grade scientific work himself and has stimulated a great deal more among students. His publications on the mechanical theory of stringed instruments have made him an internationally known authority, upon the subject about which he is speaking. This in itself is enough to make the lecture one of great interest, but Dr Raman has in addition so much personal enthusiasm for his subject, so fine a command of the English language, and so great an ability to present a subject in an entertaining and clear manner that he is an exceptionally interesting speaker. He has been lecturing this fall at the Institute upon the subject of 'Thermodynamics,' but has consented to speak at this time upon his work on stringed instruments because of its greater popular interest. He will illustrate his lecture with a number of unusual experiments on stringed instruments of various sorts.
>
> The lecture will be given in the lecture hall of the Norman Bridge Laboratory of Physics from seven to eight o'clock, Friday evening, December 12th. It is open to the public without charge."

Raman returned to Calcutta in February 1925 after visiting *en route* several countries of Western Europe to meet some of the great

leaders in physics, such as Niels Bohr, Max Planck, Charles Fabry, Kai Siegbahn and others.

Raman's first two visits abroad and the contacts he made with many scientific men and institutions during these visits brought about a very wholesome change in his habits and methods of work. Previously, he used to work for very long spells, without regard to day or night, oblivious to his needs of food, rest etc. After his foreign experiences, the pattern of his working became more regular and systematic. He developed more business-like habits in getting through his very heavy work-load of scientific research as well as direction of his many pupils. Regular hours for meals and short spells of relaxation in the evenings must have been a great relief to Lady Raman.

After Raman became FRS, the authorities of the Calcutta University were pleased to augment his salary. According to L. A. Ramdas, he acquired a horse and carriage about 1924, thus freeing himself from dependence on taxis. The carriage was black, the horse was chestnut brown and there was a syce to take care of both and also act as driver. It was a very presentable set-up. Often, while taking his evening drive, and if Lady Raman was not accompanying him, he would invite one of his senior scholars to keep him company.

Ramdas describes the experience of an outing with Raman so:

> "The evening drive usually led to the Calcutta Maidan, stopping somewhere near the statue of Lord Kitchner or Lord Roberts. Getting down, Prof. Raman would take a brisk walk towards Fort William and then take some quick jerks of 'Kasrat' and 'Dand' for exercise. He would then walk back to his carriage and drive home. On the occasion when I was with him, while walking back to the carriage at a distance of half-a-mile, he suddenly asked for the exact time. I said 7.20 p.m. He asked me if I had a watch. I said 'No' but pointed at the distant tower clock of Whiteaway and Laidlaw. He said that it takes him exactly 12 minutes to cover the distance and would check if I was right. To my great relief the time was 7.32 when we reached the carriage! He complimented me on what he called my excellent eye-sight. On the return drive we had a very interesting discussion on our current

researches at the Association, during which many fresh lines of investigation cropped up. I did not know how the time passed. We arrived at the Association by 8 p.m. My home being close to Prof. Raman's, we both went home by the famous back-gate for which I was one of the privileged few to possess the freedom of the key."

Discovery of the Raman Effect

In 1923, a detailed study of the scattering of light in water was taken up by K. R. Ramanathan, one of the research scholars who worked under Raman. Sunlight was focussed on the liquid contained in a flask, and the scattered light was observed as a track in the transverse direction. By the use of complementary filters, in the incident and scattered directions, a residual intensity was observed, which Ramanathan described as a 'weak fluorescence' due to the presence of impurities in the fluid. However, even after repeated distillation of the liquids, the 'weak fluorescence' persisted undiminished. Raman was not satisfied with the explanation and felt it might be something analogous to the Compton effect in X-ray scattering which had just then been discovered.

Two years later, K. S. Krishnan, another research scholar under Raman, observed the same phenomenon while studying the scattering of light in 65 different carefully purified liquids. He also made another important observation, that the new radiation was partially polarised, unlike ordinary fluorescence, which is unpolarised. The technique used for observing the new phenomenon made use of a beam of sunlight, a condensing lens of large aperture, a flask containing the liquid and a set of complementary filters, *i.e.* a violet-blue filter in the path of the incident beam and a greenish-yellow filter in the path of the transversely scattered light.

S. Venkateswaran, a part-time research worker at the Association, continued the work of K. S. Krishnan in the summer of 1925. He attempted to photograph the spectrum of the scattered light using sunlight passed through coloured filters, but was unable to report any decisive results. Raman, under whose guidance all this work was conducted, was not at all satisfied with the explanation that the feeble

residual scattering was due to fluorescence appearing in the spectrum in a region different from that of the incident beam. He suspected it was an entirely new type of secondary radiation, quite distinct from the usual fluorescence which was normally of high intensity and unpolarised.

The award of the Nobel Prize to Compton in 1927 acted as a great impetus to Raman to seek an analogous effect with light. One of Raman's pupils during the Calcutta days, B. N. Sreenivasiah, gives this eyewitness account of what he saw and heard at the Association one day towards the end of 1927:

> "On a November evening in 1927, while I was at Calcutta after an examination and interview at Delhi, I visited the Association at Calcutta to pay my respects to Prof. Raman. His elder brother, Shri C. Subrahmanya Ayyar (father of the famous Astrophysicist, Prof. S. Chandrasekhar), was also with Prof. Raman when I entered his office. Soon after I went in, Dr K. S. Krishnan rushed in and excitedly informed Professor of the announcement in the evening papers that Prof. A. H. Compton had been awarded the Nobel Prize in Physics for his discovery of the Compton Effect in X-Rays. On hearing this news, Prof. Raman beamed with delight and burst out in his characteristic fashion: 'Excellent news.... very nice indeed. But look here, Krishnan. If this is true of X-Rays, it must be true of light too. I have always thought so. There must be an optical analogue to the Compton Effect. We must pursue it and we are on the right lines. It *must* and shall be found. The Nobel Prize must be won'."

And Sreenivasiah goes on to record how only a few months later he attended an address Prof. Raman delivered in Bangalore on *The New Radiation.*

For some years these studies seem to have been kept in the background, while Krishnan engaged himself in some theoretical problems. In the winter of 1927, Raman went on a vacation to Waltair, the university town on the coast of what is now Andhra Pradesh. He had the Compton Effect on his mind and started working on it in Waltair. He derived a formula for the Compton scattering using

the classical theory and this helped him to realise that the 'weak fluorescence' might be the incoherent scattering with a change of wavelength, analogous to the Compton scattered radiation. Back from vacation and with new insights, Raman decided to find a satisfactory solution to the problem and asked Krishnan to stop his work on theoretical problems and start more intensive experimental studies on the anomalous scattering in liquids and vapours. He put Venkateswaran and Krishnan on purifying the liquids and got them to repeat the observations. In January 1928 the former found that in pure glycerine the scattered light was greenish in colour instead of the usual blue, and that the radiation was strongly polarised. This gave them a fresh impetus to attack the problem.

Raman and Krishnan set up a better scattering set-up to examine the scattered intensity. They used a powerful beam of sunlight, focussed by an 18 cm telescope objective lens combined with a short focus lens. This was passed through a blue-violet filter and then through the liquid (contained in a sealed flask) purified by repeated double distillation *in vacuo*. When a second filter of green glass, which was complementary in colour to the blue-violet filter, was placed in the path of the incident beam, no track of the scattered light was visible in the transverse direction. When the same was placed between the bulb and the observer, the track within the liquid continued to be visible, though less brightly.

Krishnan confirmed on February 7, 1928, the presence of 'weak fluorescence' observed by Ramanathan earlier in a number of organic liquids and vapours. Nearly 80 different aromatic, aliphatic and inorganic liquids were examined and the effect was seen in all cases, indicating thereby the universal character of the phenomenon. It was shown to be distinctly different from the usual fluorescence, because of its feebleness and strong polarisation which was nearly the same as that of the unmodified scattered light.

Raman personally verified all these observations and was very excited. Krishnan noted in his diary, that on the night of February 7th, Professor Raman rushed to Krishnan's residence to tell him that the observations they had made that morning were related to the

Kramers–Heisenberg process for which they had been looking all these years. They christened the effect 'modified scattering'.

Two days later, Raman and Krishnan detected the new radiation in vapours of ether and amylene. They soon realized that they were dealing with a new phenomenon of a fundamental character and communicated their conclusions by cable to *Nature* on February 16, 1928. In a letter entitled 'A New Type of Secondary Radiation', which was published on March 31, 1928, they repeated the arguments used in Raman's classical derivation of the Compton effect and suggested that the modified radiation could arise from the fluctuations of the molecules from the normal state. Raman and Krishnan succeeded in detecting the new radiation and in observing its partial polarisation in a number of organic vapours as well as in the gases CO_2 and N_2O. The modified scattering was easily detected in vapours such as ether and pentane at higher temperatures and consequent higher vapour pressures. Its polarisation was quite strong and was comparable with the polarisation of ordinary scattering.

While continuing further studies on the subject, Raman and Krishnan, on the afternoon of February 28, 1928, examined the influence of the wavelength of the incident light on the phenomenon. Using incident radiation of a narrower range of wavelengths brought about by a combination of blue-violet filter and a piece of uranium glass, they examined the scattered track through a direct vision spectroscope. To their great surprise they found that the modified scattering was separated from the scattering corresponding to the incident light by a dark space. Still, the experiments were performed with sunlight.

Further work carried out on that day was described by Raman himself in an address given on March 16th that same year in Bangalore. He said:

> "This encouraged me", "to take up observations with a monochromatic source of light. A quartz mercury lamp, with a filter which completely cuts out all the visible lines of wavelength longer than the indigo line 4358 A.U., was found to be very effective. When the light

from such a lamp was passed through the bulb containing a dust-free liquid, and the spectrum of the scattered light was observed through a direct vision spectroscope, it was found to exhibit two or more sharp bright lines in the blue and green regions of the spectrum. These lines were not present in the spectrum of the incident light or in the unfiltered light of the mercury arc and are thus manufactured by the molecules of the liquid."

Krishnan and Venkateswaran were working with Raman at the time of the discovery and thus had the distinction of knowing about the discovery first. Most of the other scholars in the laboratory subsequently had the opportunity of seeing this phenomenon on that day. By this observation, the discovery of the new effect was complete. Raman's student Ramdas first called the phenomenon the 'Raman Effect' in his paper, *The Raman Effect and the Spectrum of the Zodiacal Light*, published in *Nature*, Vol. 122, p. 57, July 1928.

Prof. Raman once told me that he first saw the effect in benzene through the direct vision spectroscope. He demonstrated this to me one day at the Raman Research Institute. He also said that the viewer should be in the dark room for a while and rest the eyes to see the effect. And surely it was there in benzene. I could see the Raman line in diamond also.

The following extract from Krishnan's diary conveys the intense excitement that prevailed at the time the discovery was made and shows how closely Raman followed the experiments that uncovered the mystery:

"*5th February, 1928*: For the last 3 or 4 days, I have been devoting all my time to fluorescence. The subject promises to open out a wide field for research, since, at present, there is no theory of fluorescence which could explain even the outstanding facts.

Studied anthracene Vapour. It exhibits strong fluorescence which does not show any polarisation when viewed through a double image prism. Professor has been working with me all the time.

Recently, Professor has also been working with Mr. Venkateswaran on the fluorescence exhibited by many aromatic liquids in the near ultra-violet region present in sunlight and the fluorescence of some of the liquids are found to be strongly *polarised.* However, in view of the fact that the fluorescence of anthracene vapour does not show any polarisation, Professor has asked me to verify again his observations on the polarisation of liquids.

7th February, Tuesday: Tried to verify the polarisation of the fluorescence exhibited by some of the aromatic liquids in the near ultra-violet region. Incidentally, discovered that all pure liquids show a fairly intense fluorescence also in the visible region, and what is much more interesting, all of them are strongly polarised; the polarisation being greater for the aliphatics than for the aromatics. In fact, the polarisation of the fluorescent light seems in general to run parallel with the polarisation of the scattered light, *i.e.,* the polarisation of the fluorescent light is greater the smaller the optical anisotropy of the molecule.

When I told Professor about the results, he would not believe that *all liquids* can show *polarised* fluorescence and *in the visible region.* When he came into the room, I had a bulb of pentane in the tank, a blue filter in the path of the incident light, and when he observed the track with a combination of green and yellow filters he remarked, "You do not mean to suggest, Krishnan, that *all that* is fluorescence". However, when he transferred the green yellow combination also in to the path of the incident light, he could not detect a trace of the track. He was very much excited and repeated several times that it was an *amazing result.* One after another, the whole series of liquids was examined and every one of them showed the phenomenon without exception. He wondered how we missed *all that* five years ago.

In the afternoon, took some measurements on the polarisation of fluorescence.

After meals at night, Venkateswaran and myself were chatting together in our room when Professor suddenly came to the house (at about 9.00 p.m.) and called for me. When we went down, we found

he was much excited and had come to tell me that what we had observed that morning must be Kramers-Heisenberg Effect we had been looking for all these days. We were talking in front of our house for more than a quarter of an hour when he repeatedly emphasised the exciting nature of the discovery.

8th February, Wednesday: Took some preliminary measurements of the polarisation of the modified scattering by some typical liquids.

9th February, Thursday: Set up this morning the long telescope and made preliminary arrangements for observing the effect with vapours. Before the arrangements were completed, Professor left for the College for his lecture.

In the afternoon, tried *ether vapour* and it was surprising that the modified radiation was very conspicuous. Tried a number of others in quick succession without however the same success.

When Professor came from the College at about three, I announced to him the result; and there was still enough sunlight to see for himself. He ran about the place shouting all the time, that it was a first-rate discovery, that he was feeling miserable during the lecture because he had to leave the experiment, and that, however, he was fully confident that I would not let the grass grow under my feet till I discovered the phenomenon in gases. He asked me to 'Call in everybody in the place to see the Effect' and immediately arranged in a most dramatic manner, with the mechanics, to make arrangements for examining the vapours at high temperatures.

Evening was busy, and when Professor returned after his walk he told me that I ought to tackle big problems like that and asked me to take up the problem of the experimental evidence for the spinning electron after this work was over.

10th February to 15th February: Studied a number of vapours, though a number of them showed the Effect, nothing definite could be said regarding the polarisation of the modified scattering.

16th February, Thursday: Studied today pentane vapour at high temperature and it showed a conspicuous polarisation in the modified

scattering. We sent a note today to *Nature* on the subject under the title "A New Type of Secondary Radiation".

17th February, Friday: Professor confirmed the polarisation of fluorescence in pentane vapour. I am having some trouble with my left eye. Professor has promised to make all observations himself for some time to come.

19th February to 26th February: Studied a number of other vapours.

27th February, Monday: Religious ceremony in the house. Did not go to the Association.

28th February, Tuesday: Went to the Association only in the afternoon.

Professor was there and we proceeded to examine the influence of the wavelength of the incident-light on the phenomenon. Used the usual blue violet filter coupled with a uranium glass, the range of wavelengths transmitted by the combination being much narrower than that transmitted by the blue violet filter alone. On examining the track with a direct vision spectroscope we found to our great surprise the modified scattering was separated from the scattering corresponding to the incident-light by a dark region.

This encouraged us to use monochromatic incident-light. Using the mercury arc as source we got a number of sharp lines in the scattered light which were not present in the spectrum of the incident-light."

The announcement of the discovery was made to the Associated Press the following day. Krishnan photographed the first Raman spectrum with a Hilger Baby Quartz Spectrograph in which both the Stokes and anti-Stokes components were recorded. The note sent to *Nature* on March 8th by Raman and Krishnan announcing the discovery was rejected by a referee, but the editor, Sir Richard Gregory, published it in the April 21st issue, accepting the responsibility. Raman gave a full account of the discovery in public, in an address delivered before the South Indian Science Association at Bangalore on March 16, 1928. This address, entitled *A New Radiation*,

was written immediately on his return to Calcutta, printed overnight, and one thousand reprints were posted the same day to scientists all over the world. Raman and Krishnan quickly realised the nature of the phenomenon and left out the analogy with the Compton effect in subsequent publications. Soon the scientific world got on to the discovery and the Raman Effect became an active field of research.

Professor Chandrasekhar of the University of Chicago, a nephew of Raman and at that time a student in the first year physics honours at Presidency College, Madras, recalls Raman's visit to their home in Madras on his way to Bangalore to announce the discovery. "I remember very well Raman visiting us *en route* to Bangalore, where he was to announce the discovery of his effect in an address entitled *A New Radiation*, before the South Indian Science Association on March 16, 1928. He was clearly in great form and he showed us the first spectra of the effect. He was obviously enthralled that he had discovered the optical analogue of the Compton effect for which discovery Compton had received the Nobel Prize in 1927. I remember someone asking him what could have happened if Raman had discovered his effect a year earlier. His immediate response was, 'Then I should have shared the Nobel Prize with Compton and I should not have liked that; I would rather receive the whole of it'.

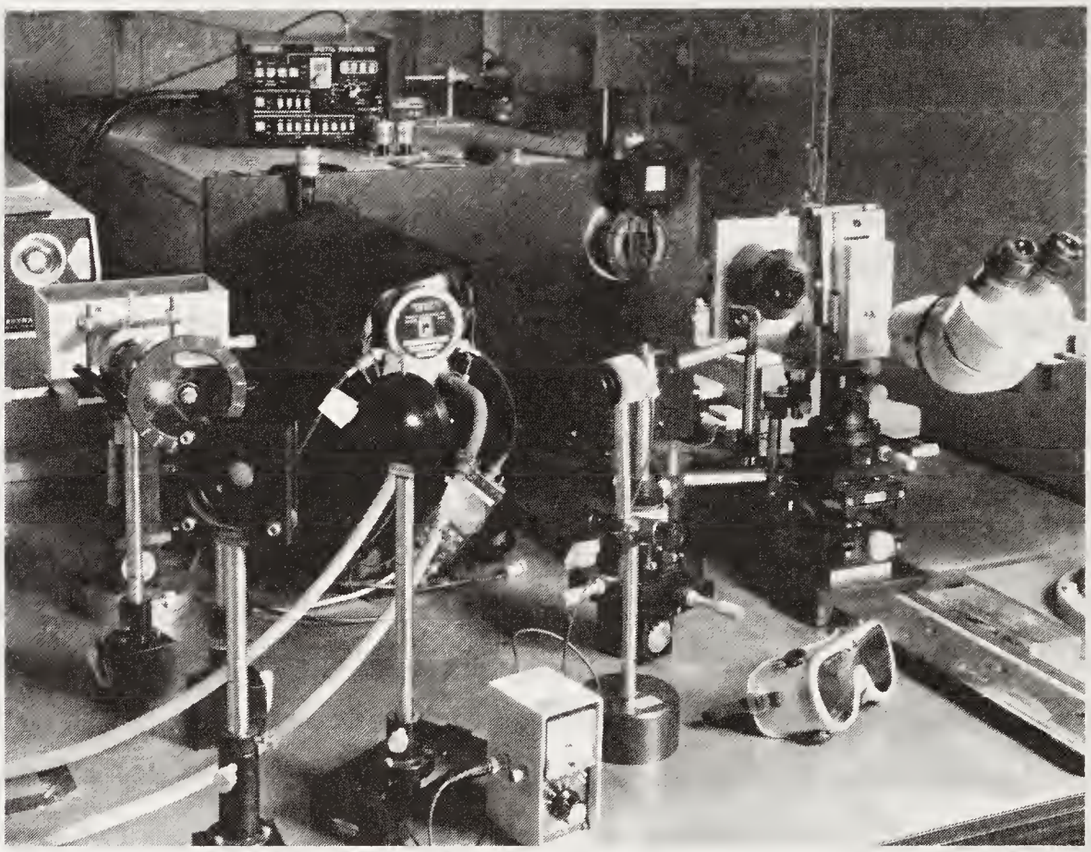
Prof. Chandrasekhar spent April, May and June, 1928, in Calcutta as well as April and May 1929. He records that he became good friends with many of Raman's associates and especially with Krishnan. "The one dominating impression which was made on me at that time and which has remained with me is the exhilarating one of being with a group of physicists in the joy of what everyone recognised as a great discovery", he remembers.

It is of interest to note here that almost at the same time as Raman was carrying out his crucial experiments, work on similar lines was going on in France and Russia. Rocard in France had anticipated, from his theoretical work, a change of wavelength in light scattering due to atomic vibrations of molecules, and Cabannes and Rocard were looking for the effect in the light scattered by gases. Gases are poor scatterers and hence they failed to observe the effect, whereas

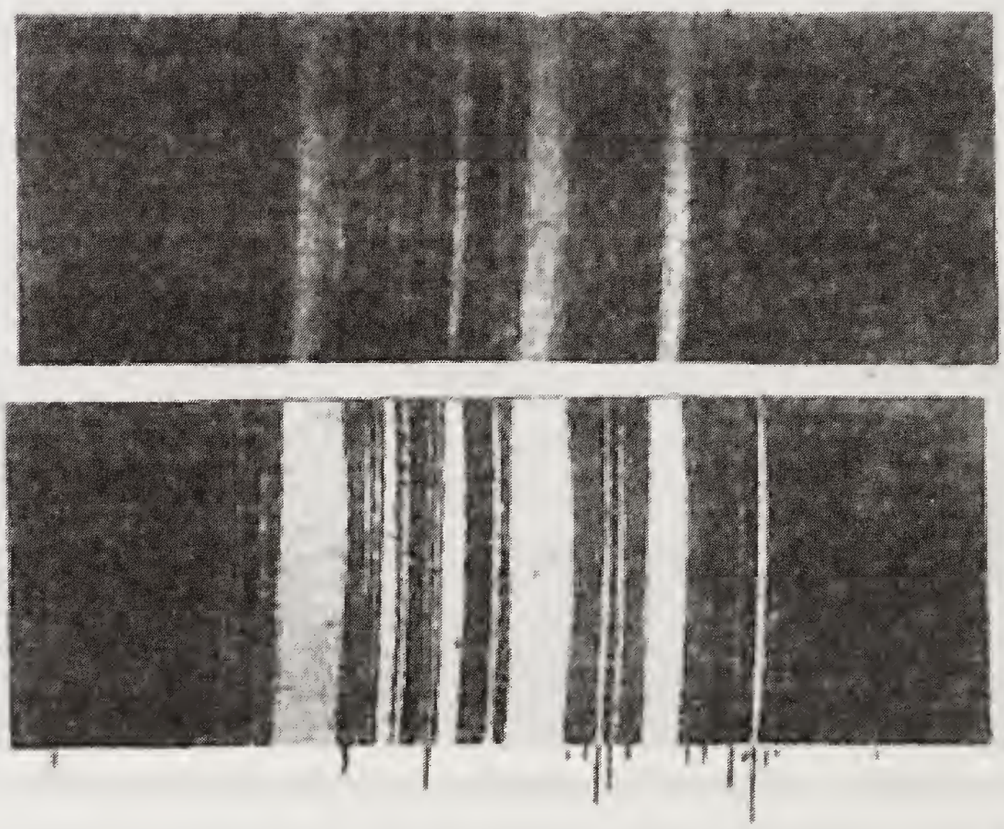
Raman's work was done with liquids which turned out to be strong scatterers. When Raman's first two papers were seen by the French group they immediately recognized the nature of the phenomenon and quickly realised its importance to chemical physics.

Quite independently, Landsberg and Mandel'shtam had been working on light scattering in crystalline quartz and, within a short time of Raman's announcement of the discovery, these two Russian physicists came out with their announcement of having observed a modified line in the scattered spectrum. Raman, however, had clearly established his priority. From the very beginning he held the view that scientific results should find prompt publication and he practised this throughout his life. It was precisely for this reason that he created the *Indian Journal of Physics* in Calcutta and started the *Proceedings of the Indian Academy of Sciences* when he shifted to Bangalore.

Raman with his experimental apparatus used in the discovery of the Raman effect.



A modern laser Raman spectrometer.



First Raman spectrum of benzene, recorded with mercury arc.

The apparatus used by Raman for his discovery consisted of a mirror for deflecting sunlight, a condensing lens, a pair of complementary glass filters, a flask containing benzene and a pocket spectroscope, the total cost of which would not have been more than Rs. 500. It could also be inferred from the account narrated above that the discovery was not the result of an accident, but was the culmination of seven years of systematic and sustained work carried out with devotion by Raman and his band of students. The achievement is all the more creditable when it is realised that the support for scientific research in India in those times was so meagre.

The history of the discovery of the Raman Effect also has many lessons for the aspirants of Science. It is not very expensive equipment that is important for making a capital discovery but the calibre of the scientists, sustained effort and single-mindedness. Hardly any discovery appears right away in its clear and final form. Nature reveals its secrets bit by bit. Great discoveries appear incredibly simple only after someone has made them and explained them.

Sommerfeld's visit to Calcutta

Arnold Sommerfeld's visit to India in the latter half of 1928 was very significant as he was the first physicist of immense stature to come to Raman's laboratory and see a demonstration of the new discovery. There were some who expressed doubts as to whether Raman could have observed such a weak effect. Sommerfeld came in October 1928 and Raman demonstrated to him the light-scattering effect he had discovered. Sommerfeld was tremendously impressed by the experimental demonstration and the seriousness and dedication with which Raman had been pursuing his researches.

When Arnold Sommerfeld accepted the invitation to spend the first few months of 1929 as a guest professor in the United States of America, he was firmly resolved "not to take the ordinary way but the extraordinary one *via* the far East". He was specially attracted to India, for he had heard about its wonders, its ancient civilisation and its lofty religious and philosophical system. Sommerfeld was also impressed with the strong shoots of modern physics emerging from

Arnold Sommerfeld with C. V. Raman (right) and K. S. Krishnan (left). Picture taken at Calcutta in 1928. (Photo courtesy of Deutsches Museum, Munich, supplied very kindly by Dr G. Torkar of Ludwig-Maximilians Universität, Munich)

this part of the world; he had in mind the emergence of Raman as a world-class scientist on the verge of discovering the light-scattering effect. So Sommerfeld planned his detour to India; and this was before Raman had actually performed the decisive experiment.

Raman had wired Sommerfeld on February 11, 1928: "Calcutta University inviting you, lecture honorarium thousand rupees, kindly wire date arrival India." When boarding the steam-boat in Genoa on August 21, 1928, Sommerfeld carried numerous invitations, to lecture on Modern Atomic Physics at Indian universities, as well as an itinerary prepared by Meghnad Saha. As soon as he arrived in India he was taken ill and had to be hospitalised in Bangalore for two weeks. He arrived in Calcutta, his main destination in India, on October 4, 1928. Several entries in his diary of the tour speak of his time in Calcutta.

"*October 4*: Grand reception at Howrah Station. Raman, Bose, Krishnan, Sen, Gosh., Mitra...also the German vice-consul Eberl at whose

> place I stay...3 beautiful rooms with bathroom...hibiscus flowers in blossom up to the first floor...then Bose takes me to Raman's institute...(he) shows me papers on diffraction...
>
> *October 6*: 8 o'clock in the morning, first special lecture on Kepler problems, discussion until 10'clock...eventually the Raman effect visually: blue filter and compl. screen, now put in front of the incident light, then in front of the scattered light: difference...
>
> *October 7*: Sunday...Wonderful lecture by Raman (also the rotations of the molecules can be seen unresolved as modified rad.)...
>
> *October 8-13*: Lectures daily from 8-10 with lively discussions... I saw scattering blue-green on an iceblock in the institute, obvious modified scattering. Everything in the institute is very good, but bathroom terrible...

Sommerfeld's interest in India was not restricted to physics. He was deeply interested in its art as well as the life and the customs of its people. He left Calcutta on October 14, 1928, to visit a few other places in Northern India, such as Benares and Agra. He preferred a trip to Shantiniketan to a sight-seeing tour through Delhi, following the "kind" invitation by the poet and philosopher Rabindranath Tagore, winner of the Nobel Prize for Literature. With Tagore, whom he put on a par with Goethe (Sommerfeld, a humanist, was an ardent admirer of Goethe), he enjoyed a day of peace, "the peace of an Indian autumn". On October 26th, Sommerfeld left India from Calcutta: "With two cars to the harbour. Again a garland of Krishnan and flowers from the X-ray man..."

During the voyage, he put down the conversation he had with Raman, on the eve of his departure, and his own experiences. It is a record in which he comments critically upon India's economic and political conditions and her difficult relations with Great Britain. He left India "in deepest affection for the highly-gifted, unhappy nation" and "with sincere gratitude for the many acts of friendliness and honourings". As a sign of his special gratitude, he proposed Raman as a candidate for the Nobel Prize. Raman, who learned this, thanked Sommerfeld effusively: "I do not know how to express adequately

my gratitude for this act of kindness. The literature of the new effect is growing at a great pace. I hope the Nobel Committee may give a favourable decision in December next if my name is put before them on the occasion also."

After receiving the Nobel Prize, Raman visited Sommerfeld in Munich. He was received with great joy: "We welcome our guest not only as a successful scientist and discoverer but also as a representative of the age-old and now rejuvenated culture of the Orient which trustfully cooperates with the Occidental culture and strives for the same ends."

Raman was proposed for the Nobel Prize for Physics in 1929 by N. Bohr and C. Fabry and in 1930 by E. Bloch, N. Bohr, L. and M. deBroglie, O. Khvolson, J. Perrin, R. Pfeiffer, E. Rutherford, J. Stark and C. T. R. Wilson. Sommerfeld's name does not appear in the list of nominators. However, it is likely that he wrote to the Committee and the recommendation did not get into the official records. Raman was awarded the Prize in 1930 and news of the award was hailed universally. Raman, accompanied by Lady Raman, left for Stockholm, to receive the Nobel Prize, on December 10, 1930. He was 42 years old.

The meetings of the Nobel Committee are held in the highest secrecy and the awards announced in November, only about a month before the prize-giving ceremony in mid-December. Given the time it would have taken to reach Europe by steamship in those days, it would have been surprising if Raman could have reached Stockholm in time for the ceremony if he had arranged for passage only after receiving the telegram. It is now a historical fact, however, that Raman had, in anticipation, booked tickets for himself and his wife in July that year and it was this that enabled them to reach Stockholm in early December!

Stockholm and the Nobel ceremony

A vivid eyewitness account of this visit and the Nobel ceremony in Stockholm was published in the 'Raman Number' of the *Calcutta Municipal Gazette* when the Calcutta Corporation presented an *Ad-*

dress to Prof. Raman in 1931. This fascinating article, entitled 'A week in Stockholm', was written by Lady Raman and in it she said:

> "The week we stayed in Sweden was one long festival. If garlanding were as much part of a ceremonial function in Sweden as in India, the garlands we would have collected would have been innumerable. But the more common thing there is photographing. Newspaper reporters were at us even on the boat taking us to Sweden across the Baltic. I do not know in what manner the rest of the world looks on the Nobel Laureates, but the Swedish certainly focus their eyes on them. Parties and gatherings to meet the Nobel Prizemen are held without intermission. In India, hospitality is considered to be a religious duty, but it is in Sweden that I saw what hospitality can be.
>
> Our stay in Stockholm extended for a week from the 9th to 16th December, 1930. We arrived by train at Stockholm, the capital city of Sweden, at 8 o'clock in the morning of the 9th December. The platform was crowded with people waiting to receive the guests. There were at least ten cameras ready for exposure. In northern latitudes in winter, sunlight is a rare phenomenon, but days and nights are made equally bright by thousands of electric lights. Everybody who spoke to us expressed sorrow that it being winter, their country was not looking its best but was dark and bleak, and that we should see it in spring shining in sunshine. As their sun never rises high up in the skies, one can well understand their fondness for sunshine, but if they had enjoyed the Indian sun of April and May, I am sure their partiality for the sun would get moderated. Owing to the low actinic value of electric light they always use flash-light for taking photographs. The suddenness and attendant noise as of a cracker startle newcomers, but we soon got used to it. Not being white-skinned, we could not mix with the natives of the country without being recognised; moreover our multi-coloured Indian dress was making us conspicuous to every eye.
>
> The Scandinavian is of great height and size, and I was somewhat shy of my comparatively short stature.
>
> Even after reaching the hotel, the stream of photographers and newspaper reporters continued to show us their attention. Indians are rare phenomena in Scandinavia and our photographs were published *ad nauseam*. It was very difficult to get rid of the newspaper men. They

must hear about Indian politics; my husband talked about educational matters, but what was I to talk about? I could only speak on the habits, customs and beliefs of our country. It certainly interested them and they were surprised about the Hindu ways of living, as I was about their sunless days."

After referring to the tea at the British Embassy and the dinner at the Swedish Academy of Sciences, to which Professor and Lady Raman were escorted by Dr E. Nobel, a relative of Alfred Nobel, Lady Raman described the Nobel Prize Award Ceremony:

"The award of the Nobel Prizes took place on the 10th December between 4 and 7 p.m. If I shut my eyes, I can still see as in a dream the great concert hall of Stockholm, decorated with flowers and flags, filled with more than 4,000 people, the King and Queen of Sweden and the Royal family occupying the first seats. The Nobel Laureates then entered the Hall, each accompanied by a Professor in his own subject and followed by such Nobel Laureates of previous years as were present in Stockholm and the members of the Academy. As the procession entered, the whole audience stood up and remained standing until the Laureates took their seats amidst a fanfare of trumpets. The Laureates of the year were seated on one side of the dais and their introducers on the opposite side. The Secretary of the Academy of Sciences read a report and gave a brief account of Nobel's life. Dr Pleijel, Professor of Electro-Technics in the University of Stockholm, then rose and spoke for twenty minutes on my husband's investigations on the scattering of light and the new effect that had been discovered by him. (*Note*: This speech is given in its entirety at the end of this section.) He then addressed my husband and said,

'Sir Venkata Raman, The Royal Academy of Sciences has awarded you the Nobel Prize in Physics for your eminent researches on the diffusion of gases and for your discovery of the effect that bears your name. The Raman effect has opened new routes to our knowledge of the structure of matter and has already given most important results.'

'I now ask you to receive the prize from the hands of His Majesty.'

On Sir Chandrasekhara rising to receive the Prize, the whole audience, including the King, stood up and the British flag was held aloft. The

Laureate then approached the Royal Seat and bowed before the King, who took him by the hand and presented him the Nobel Medal, Prize and Diploma. This was attended with loud cheering and was followed by orchestral music for about fifteen minutes.

Then followed in succession the addresses on the work of the other Laureates and the award of the medal, prize and diploma to each of them.

The whole ceremony took about 3 hours and was followed by the Nobel banquet which took place at the *Mela*, a beautiful building picturesquely situated by the side of the Malar lake. The banqueting hall can accommodate about 400 guests. The Nobel Laureates sat at the Royal Table. The dinner was of the most lavish scale. Wine flowed freely. A few vegetarian dishes had been considerately provided for us. When it came to the drinking of health, we had our cups filled with water. In replying to the toast, Sir Raman spoke of the glories of ancient India. He spoke of the great renunciation of Buddha, the Royal ascetic and world teacher, and of his message of non-violence and love which embraced all living creation. It was nearly twelve when the party broke up.

Next day, the Nobel lectures were delivered at the University. Each prize-winner spoke on his own work. These lectures are later collected in the form of a book. In the evening, there was a reception by the King and Queen at the Palace. After dinner, the guests were shown round the library and art collections and time passed pleasantly in conversation with various members of the Royal family. We met there a grandson of Tolstoy who kindly took us to various places of interest.

The 12th December was a very cold day. A chill wind was blowing. In the night we witnessed an interesting popular festival called Lucia-light. There was a procession led by a young maid with a crown of lighted candles on her head. The legend was that she was heralding the advent of snow and was bringing light for the dark winter days ahead. Strangely enough, when we woke up next morning, there was a sheet of white snow all over the city, greatly enhancing its beauty. Next to Venice, Stockholm is considered to be the most beautiful city in Europe, with its large clear fresh-water lake in its centre, magnificent buildings on the shores of the lake and its clean, broad streets.

As we had few further social engagements, we walked that morning some distance out of the city to enjoy the beauty of the snow scenery.

The snow had transformed, as if by magic, the dark artificially lit city and surroundings into a scene of ethereal beauty.

Next day (14th December) we were invited to dinner at the house of the President of the Swedish Academy, Dr Petterson. It appears that when the poet Rabindranath Tagore was there, he sang some Indian songs and the memory of it was still fresh in their minds. Somehow, they induced my husband to sing! After one more day of leisured sight-seeing we left for Upsala on the 16th, where we were the guests of Prof. Siegbahn and his lady."

After his return to India from the Nobel ceremony in Stockholm, Prof. Raman had to face vast crowds of admirers, anxious to see and hear the great Nobel Prize-winner. He became such a popular figure in India that, wherever he went, he often had to address several meetings of citizens and students on his latest researches and on science in general. This rush of speeches and public engagements pursued him all through his long life.

The Nobel Presentation Speech by Professor H. Pleijel, Chairman of the Nobel Committee for Physics of the Royal Swedish Academy of Sciences:

"Your Majesty, Your Royal Highnesses, Ladies and Gentlemen.

The Academy of Sciences has resolved to award the Nobel Prize in Physics for 1930 to Sir Venkata Raman for his work on the scattering of light and for the discovery of the effect named after him.

The diffusion of light is an optical phenomenon, which has been known for a long time. A ray of light is not perceptible unless it strikes the eye directly. If, however, a bundle of rays of light traverses a medium in which extremely fine dust is present, the ray of light will scatter to the sides and the path of the ray through the medium will be discernible from the side. We can represent the course of events in this way; the small particles of dust begin to oscillate owing to electric influence from the ray of light, and they form centres from which light is disseminated in all directions. The wavelength, or the

number of oscillations per second, in the light thus diffused is here the same as in the original ray of light. But this effect has different degrees of strength for light with different wavelengths. It is stronger for the short wavelengths than for the long ones, and consequently it is stronger for the blue part of the spectrum than for the red part. Hence if a ray of light containing all the colours of the spectrum passes through a medium, the yellow and the red rays will pass through the medium without appreciable scattering, whereas the blue rays will be scattered to the sides. This effect has received the name of the 'Tyndall effect'.

Lord Rayleigh, who has made a study of this effect, has put forward the hypothesis that the blue colours of the sky and the reddish colouring that is observed at sunrise and sunset is caused by the diffusion of light owing to the fine dust or the particles of water in the atmosphere. The blue light from the sky would thus be light scattered to the sides, while the reddish light would be light that passes through the lower layers of the atmosphere and which has become impoverished in blue rays owing to scattering. Later, in 1899, Rayleigh threw out the suggestion that the phenomenon in question might be due to the fact that the molecules of air themselves exercised a scattering effect on the rays of light.

In 1914 Cabannes succeeded in showing experimentally that pure and dustless gases also have the capacity of scattering rays of light.

But a closer examination of scattering in different substances in solid, liquid, or gaseous form showed that the scattered light did not in certain respects exactly follow the laws which, according to calculation, should hold good for the Tyndall effect. The hypothesis which formed the basis of this effect would seem to involve, amongst other things, that the rays scattered to the sides were polarised. This, however, did not prove to be exactly the case.

This divergence from what was to be expected was made the starting-point of a searching study of the nature of scattered light, in which study Raman was one of those who took an active part. Raman sought

to find the explanation of the anomalies in asymmetry observed in the molecules. During these studies of his in the phenomenon of scattering, Raman made, in 1928, the unexpected and highly surprising discovery that the scattered light showed not only the radiation that derived from the primary light but also a radiation that contained other wavelengths, which were foreign to the primary light.

In order to study more closely the properties of the new rays, the primary light that was emitted from a powerful mercury lamp was filtered in such a way as to yield a primary light of one single wavelength. The light scattered from that ray in a medium was watched in a spectrograph, in which every wavelength or frequency produces a line. Here he found that, in addition to the mercury line chosen, there was obtained a spectrum of new sharp lines, which appeared in the spectrograph on either side of the original line. When another mercury line was employed, the same extra spectrum showed itself round it. Thus, when the primary light was moved, the new spectrum followed, in such a way that the frequency distance between the primary line and the new lines always remained the same.

Raman investigated the universal character of the phenomenon by using a large number of substances as a scattering medium, and everywhere found the same effect.

The explanation of this phenomenon, which has received the name of the 'Raman Effect' after its discoverer, has been found by Raman himself, with the help of the modern conception of the nature of light. According to that conception, light cannot be emitted from or absorbed by material otherwise than in the form of definite amounts of energy or what are known as 'light quanta'. Thus the energy of light would possess a kind of atomic character. A quantum of light is proportionate to the frequency of rays of light, so that in the case of a frequency twice as great, the quanta of the rays of light will also be twice as great.

In order to illustrate the conditions when an atom emits or absorbs light energy, we can, according to Bohr, picture to ourselves the atom

as consisting of a nucleus, charged with positive electricity round which negative electrons rotate in circular paths at various distances from the centre. The path of every such electron possesses a certain energy, which is different from different distances from the central body.

Only certain paths are stable. When the electron moves in such a path, no energy is emitted. When, on the other hand, an electron falls from a path with higher energy to one with lower energy — that is to say, from an outer path to an inner path — light is emitted with a frequency that is characteristic of these two paths, and the energy of radiation consists of a quantum of light. Thus the atom can give rise to as many frequencies as the number of different transitions between the stable paths. There is a line in the spectrum corresponding to each frequency.

An incoming radiation cannot be absorbed by the atom unless its light quantum is identical with one of the light quanta that the atom can emit.

Now the Raman Effect seems to conflict with this law. The positions of the Raman-lines in the spectrum do not correspond, in point of fact, with the frequencies of the atom itself, and they move with the activating ray. Raman has explained this apparent contradiction and the coming into existence of the lines by the effect of combination between the quantum of light coming from without and the quanta of light that are released or bound in the atom. If the atom, at the same time as it receives from without a quantum of light, emits a quantum of light of a different magnitude, and if the difference between these two quanta is identical with the quantum of light which is bound or released when an electron passes from one path to another, the quantum of light coming from without is absorbed. In that case the atom will emit an extra frequency, which either will be the sum of or the difference between the activating ray and a frequency in the atom itself. In this case these new lines group themselves round the incoming primary frequency on either side of it, and the distance between the activating frequency and the nearest Raman-lines will be identical

with the lowest oscillation frequencies of the atom or with its ultra-red spectrum. What has been said as to the atom and its oscillations also holds good of the molecule.

In this way we get the ultra-red spectrum moved up to the spectral line of the activating light. The discovery of the Raman-line has proved to be of extraordinarily great importance for our knowledge of the structure of molecules.

So far, indeed, there have been all but insuperable difficulties in the way of studying these ultra-red oscillations, because that part of the spectrum lies so far away from the region where the photographic plate is sensitive. Raman's discovery has now overcome these difficulties, and the way has been opened for the investigation of the oscillations of the nucleus of the molecules. We choose the primary ray within that range of frequency where the photographic plate is sensitive. The ultra-red spectrum, in the form of the Raman-lines, is moved up to that region and, in consequence of that, exact measurements of its lines can be effected.

In the same way, the ultra-violet spectrum can be investigated with the help of the Raman Effect. Thus we have obtained a simple and exact method for the investigation of the entire sphere of oscillation of the molecules.

Raman himself and his fellow-workers have, during the years that have elapsed since the discovery was made, investigated the frequencies in a large number of substances in a solid, liquid and gaseous state. Investigations have been made as to whether different conditions of aggregation affect atoms and molecules, and the molecular conditions in electrolytic dissociation and the ultra-red absorption spectrum of crystals have been studied.

Thus the Raman Effect has already yielded important results concerning the chemical constitution of substances; and it is to foresee that the extremely valuable tool that the Raman Effect has placed in our hands will in the immediate future bring with it a deepening of our knowledge of the structure of matter."

Civic honour by the Calcutta Corporation

Among the warm tributes paid to him on his return, that of the Calcutta Corporation is noteworthy.

The Corporation Address was presented to Sir Chandrasekhara Venkata Raman on Friday, June 26, 1931, at a brilliant function in the historic Town Hall of Calcutta. The hall was elegantly decorated and illuminated, and a distinguished gathering, composed of some of the foremost citizens, was present when the city fathers, representing the public, acclaimed the Nobel Laureate.

At the head of the staircase, Prof. Raman, accompanied by Lady Raman, was received by the Aldermen, Councillors and the principal officers of the Corporation. As he entered the Hall at the head of the procession, the whole assembly stood up and greeted him with cheers.

On reaching the dais, the Mayor garlanded Sir Chandrasekhara, amid applause. As Prof. Raman took his seat, there was a shower of flowers upon him from an ingenious overhead contrivance.

To Prof. Raman's right sat the Mayor, while to his left was seated the Deputy Mayor. Distinguished guests, Aldermen, Councillors and the principal officers of the Corporation occupied other seats on the dais. The Mayor then read the Address, which was printed on *Khaddar* with gold embroidery, and presented it to Sir Chandrasekhara on an engraved silver tray. The Address was received with applause by the assembly.

Sir Chandrasekhara, who on rising received an ovation, made a striking speech in the course of which he paid a tribute to Calcutta, which, he said, has been "the intellectual metropolis not only of Bengal, or of India, but of the whole of Asia, from which has gone forth a living stream of knowledge in many branches of study".

At the end of the function, the Mayor presented the Aldermen and Councillors of the Corporation to Sir Chandrasekhara.

The Corporation offices and schools remained closed on Thursday, July 2nd, in honour of the presentation of the Corporation Address to Sir C. V. Raman. This Address read:

"Sir, We, the Aldermen and Councillors of the Corporation of Calcutta, beg to offer you our respectful congratulations on your great achievements in the domain of Science. The recent awards to you of the Nobel Prize, of the Royal Society's Medal and the Matteucci Medal, are, in each case, the first distinctions of the kind to be gained by an Asiatic man of Science, and bear unequivocal testimony to the high esteem and regard in which your contributions to knowledge are held in the world of Science. Working in an Indian laboratory, with a purely Indian training, you have achieved results of the highest value, thus demonstrating the high level of efficiency attained by this country in the matter of scientific research.

Your single-minded devotion to the cause of Science and your bold idealism will ever remain a perennial source of inspiration to your countrymen. The highest academic degrees and the lucrative position in Government service, which you won at the early age of 18, would have satisfied most ambitions. But the passion for research, which had manifested itself even at that age, impelled you to seek opportunities for its further expression and led you to give up a lucrative career for the sake of Science. Your noble ideal and example have inspired the work of your pupils, and the *Indian Journal of Physics*, of which you are the founder, is the recognised organ for recording and stimulating research in Physical Science in this country.

It is not for us to narrate the long list of your contributions to Science, but we may be pardoned for mentioning the Raman Effect by the discovery of which you have secured a permanent place in the history of modern Science. New scientific truths, basing themselves on your epoch-making discovery, are emanating from the laboratories of every civilised country and continue to glorify your name.

As a great teacher of the youth of our country, you have exhibited in a remarkable degree a wide range of intellectual interests and a gift of exposition often touching the heights of humour and eloquence.

We recall with pride and pleasure that it was through one of our eminent fellow citizens that the creative genius of the East received the

homage of the West when the Nobel Prize was attracted for the first time to Asia by the immortal works of our great national poet. We rejoice to think that by unravelling the deep mysteries of Nature, a most distinguished savant of this city has now brought to the East for the first time the highest award of the West in the field of Science.

Installed in the Palit Chair of Physics in the University of Calcutta, you have, by your success in extending the bounds of human knowledge, supplied some of the most enduring cornerstones of the Citys Temple of Learning. May you, by your continued efforts, shed further lustre on this City and bring greater glory to our Motherland, this ancient home of learning and knowledge.

We beg to subscribe ourselves, Sir, Yours in the service of the Motherland, The Aldermen and Councillors of the Corporation of Calcutta: by Bidhan Chandra Roy

Sir C.V. Raman replied:

"Mr. Mayor, Aldermen and Councillors of the Calcutta Corporation, Ladies and Gentlemen:

There are occasions when even the most cold-blooded of men finds himself deeply moved by emotion. It is possible that the ideal man of science should be just a perfect thinking machine with no sentiment or emotion in his make-up. That I am indeed far from approaching this ideal was evident on a certain occasion in Stockholm last December when the people of the coldest country in Europe tendered to a man of science from the tropic East the highest distinction in their gift. On the present occasion as well, I have difficulty in finding words in which to convey my feelings. Permit me, Sir, to express my gratitude to you and your Fellow-Councillors for what must be regarded as a supreme honour by every citizen of Calcutta.

You, Sir, have referred to my early career. It is not often that the idealism of student days finds adequate opportunity for expression in the later life of manhood. It will soon be 25 years from the date of publication of my first research work. That the scientific aspirations kindled by that early work did not suffer extinction has been due entirely

to the opportunities provided for me by the great city of Calcutta. To two men, especially, I owe a debt of gratitude that can never be repaid.

It was the late Dr Mahendra Lal Sircar, who, by founding the Indian Association for Cultivation of Science, made it possible for the scientific aspirations of my early years to continue burning brightly. Dr Sircar devoted a life-time of labour to the institution which he created and equipped in the hope that it would some day be utilised for the advancement of science in India. Its doors were open, awaiting the arrival of someone who could utilise the resources it offered. That arrival happened to be myself. Dr Mahendra Lal Sircar did not, alas, live to see his aims accomplished. He sowed that others might reap.

To another great citizen of Calcutta, a man who was most farseeing, profoundly gifted and inspired by the highest ideals, I mean the late Sir Asutosh Mookerjee, I am also under a deep debt of gratitude. Sir Asutosh ventured to ask a young and unknown Government official to throw aside the preferments of office, and devote himself to the pursuit of knowledge, under the aegis of the Calcutta University. This, on his part, was an act of great courage, whereas on mine it was just a case of following my own inclinations. But for the action which Sir Asutosh took, my scientific career would long ago have suffered an abrupt termination.

I desire to take this opportunity of expressing my gratitude also to my many friends in the city of Calcutta who have helped my work and made my task easier. Amongst them, I wish particularly to single out my distinguished friend, Sir Prafulla Chandra Ray, whom I am glad to see here today. I have always thought it a great privilege to have as my colleague in the Palit Chair of Chemistry such a distinguished pioneer in scientific research and education in Bengal as Sir Prafulla Ray. It has been invariably my experience that I could count on his co-operation and sympathy in every matter concerning my scientific work.

It has been my good fortune to have had during the past 15 years a long succession of highly gifted collaborators. To them, also, I am under a deep debt of obligation, for it is their assistance that has made possible much of the work that has emerged from my laboratory. It is generally believed that it is the students who derive benefit by working under the guidance of a Professor. In reality, the Professor benefits equally by his association with gifted students working under him. From the very first, I have acted under the firm conviction that a Professor who succeeds in attracting and inspiring a group of co-workers was also benefiting himself and rendering to the cause of Science far greater service than he could ever hope to offer in splendid isolation.

You, Sir, have referred to the fact that I never had any training in foreign laboratories or Universities. I believe myself that this was a fortunate circumstance, for it is my firm conviction that the highest inspiration for scientific work is that which comes from within one-self. It is my earnest hope that it will be possible in the near future to create opportunities in our own country for students to do the highest type of creative scientific work. In saying this, I do not for a moment suggest that we have nothing to learn from Europe or America, but surely it is better that we learn to accomplish whatever we can within our own borders.

You, Sir, have said that you desire my association with Calcutta to be a permanent one. Let me say at once that this is also my earnest desire. I consider it my great good fortune to have been a citizen of Calcutta for nearly 25 years. Some have said that research work cannot be carried on successfully except in cool climates, such as those of Bangalore or Dehra Dun. A hot day in June is not an opportune moment to enter upon praise of the physical climate of Calcutta. But from the point of view of research, there is something more important than physical climate, and that is the intellectual climate of the environment. For a hundred years, Calcutta has been the intellectual metropolis not only of Bengal, or of India, but of the whole of Asia. From Calcutta has gone forth a living stream of knowledge in many branches of study. It is inspiring to think of the long succession of scholars, both Indian and

European, who have lived in this city, made it their own, and given it of their best. It must be a profound privilege to be able to work and live in such an environment.

Of recent years I have had occasions to visit numerous laboratories abroad. Many of them are being rebuilt or re-organised, in order better to cope with the problems of science. The Rockefeller Foundation has played the part of a fairy godmother to many a scientist in Europe and America in the realisation of his scientific aims and aspirations. It is the Indian Association for Cultivation of Science which first afforded me opportunities for scientific work at Calcutta, and which has been the scene of the labours of many of my most gifted collaborators. It is my earnest desire that its laboratory and library should be re-built and re-equipped so as to make their resources comparable with those of leading institutions abroad. If that desire were accomplished, not all the appointments in India joined together and offered to me as one gift would induce me to leave this great city.

Allow me to thank you once again for the great honour you have done me."

Chapter II

To Bangalore and the Indian Institute of Science

In 1933, Raman was offered the Directorship of the Indian Institute of Science (IISc) founded by J. N. Tata. He accepted it with some hesitation. But after 25 years of living in Calcutta, Raman was naturally attracted to Bangalore for the welcome change it offered, both from the point of view of the climate and the beautiful environment. He fell in love with Bangalore so much, he made it his permanent home.

The Indian Institute of Science was set up in 1909 to conduct original research and provide advanced training in science and engineering for Indian students. To J. N. Tata, the visionary, the institution was to be the primary base for the intellectual rejuvenation and modernisation of India. But to Lord Curzon, the then Viceroy of India, this would be a seditious step against the British Raj and so he opposed its establishment. Nevertheless, five years after Tata's death, the Institute was established, and Bangalore became its home because of the farsightedness of the *Maharaja* and the Government of Mysore who offered it about 150 hectares of land and many other facilities.

The Directors of the Institute (till Raman's appointment) were always British; so were most of the early faculty. Some felt that under the tutelage of the British Resident of Mysore State, the Institute was subserving the interests of Great Britain. Even the starting

of the General Chemistry and Electrical Technology Departments was associated, by those who held this view, with the running of the British-owned Kolar Gold Fields. The effect of research and education 'appearing' at the IISc. had a tremendous effect on the country, but nationalists however were dissatisfied with the 'performance' of the Institute. They felt that, in spite of large sums of money being spent, the Institute neither catalysed industrial growth nor produced any outstanding scientific discoveries of which India could be proud.

Raman, however, felt strongly that research and advanced education could be the foundation for any economic advancement only if there was excellence of the highest order. Therefore he tried many strategies to bring about change at the Indian Institute of Science.

Being a great lover of Nature, he first sought to improve the surroundings by planting beautiful flowering trees. In this he was aided by Sir Mirza Ismail, the Dewan of Mysore, and Mr Krumbeigel, the Chief Horticulturist of Lalbagh, Bangalore's botanical garden. Even today, the campus of the Institute remains a lovely garden, though somewhat spoiled by the addition of so many buildings.

Around the time Raman moved to Bangalore, many famous scientists were fleeing Germany. Raman wanted to attract them. He felt that by inviting some of these outstanding men of science and offering them permanent positions, a great scientific movement could be created in India. He invited Max Born and nearly succeeded in appointing him to an Extraordinary Chair of Physics he created at the Institute. Raman also made an offer to Schrödinger, but he was too late, for the latter had already accepted an offer from Dublin. Many others were on his list, but before he could pursue his quest further, his strong personality and management style resulted in serious difficulties with the governing body of the Institute and he was forced to resign from the Directorship. He, however, continued as Professor of Physics until his retirement in 1948, pursuing with undiminished enthusiasm new avenues of research.

Raman developed the Department of Physics at the Institute and, with characteristic energy, turned it into an active centre for physics research. He took a large number of students and trained them as

first-class physicists, shaping their careers and destinies. He started research in diverse fields, *viz.* ultrasonics, Brillouin scattering, X-ray scattering, physics of the diamond and lattice dynamics. Light-scattering studies continued as a regular programme in his laboratory.

One of his outstanding contributions during his 15 years at the Institute concerns the diffraction of light by high-frequency sound waves. The phenomenon of ultrasonic diffraction was first discovered in 1932, by Debye and Sears in America and, simultaneously and independently, by Lucas and Biquard in France. Raman explained this phenomenon in a beautiful way. He also published several papers with Nagendra Nath as his collaborator. The so-called Raman–Nath theory not only fully explained the observed effects but indicated several interesting new ideas.

How Raman's brilliant suggestions led to the Raman–Nath theory has been described by Nagendra Nath himself:

> "One day, Parthasarathy was to give an account of the determination of the velocity of sound in organic liquids by the method of diffraction of light by ultrasonic waves. Hardly had he finished the description of the experimental set-up, than Professor raised the query — What is the number of diffraction orders expected on the basis of Brillouin's theory? — The reply was two first orders of weak intensity. What was the fact, was the next query. A number of diffraction orders not in agreement with the theory. Professor went to the board and said that the theory should be developed in a different way. A sound wave creates compressions and rarefactions. A light beam would be slowed in the region of compressions and it would move faster in the region of rarefactions, and so a plane wavefront would become a corrugated wavefront like a zinc sheet used for building purposes. Professor said that an analysis of this corrugated wavefront would explain the unexplained results. When I went to him next day giving an explanation of the results on the basis of his ideas, he said it was all correct and that started a series of papers by him and myself which has come to be known in literature as the Raman-Nath Theory."

Though Raman's outlook was essentially that of an experimental physicist, he would insist on the physical significance of every theoretical result. He had a stock in trade of certain physical results and he would liberally draw on them to explain results in a different subject altogether. Once, Max Born exclaimed, "He leaps over Mathematics".

It was in the field of lattice dynamics that Raman got involved in a bitter controversy with Born, Debye and others by strongly opposing their theories. Raman was incorrect, but he was convinced that he was right in his approach. This attitude made him highly emotional and irrational when it came to lattice dynamics. Further, it also proved counter-productive for him and he got side-tracked into an area which was not his forté. What he was, was an experimentalist *par excellence*, possessing an unusual insight when it came to optics.

Raman had a lively and life-long interest in diamonds and built up an outstanding collection. He made many scientific studies on the diamond, but unfortunately got into a controversy again.

These controversies do not diminish Raman's fine contribution made to optics, spectroscopy and crystal physics during these years. Raman and Nedungadi were the first to observe the soft mode behaviour associated with the phase transition in the α to β quartz transformation. This was almost two decades before Cochran came out with the soft mode theory for phase transitions, a theory now well known. Raman and his students also made outstanding contributions to crystal optics, *viz.* conical refraction, optical activity and other crystal optical phenomena.

During his tenure as Professor at the Indian Institute of Science, the Department of Physics was intensely active in diverse areas of physics, with Raman as its moving spirit. It was during this period that R. S. Krishnan carried out pioneering Raman scattering studies using the so-called Rasetti technique which employed the mercury resonance radiation $\lambda = 2537$Å coming out of a water-cooled quartz mercury lamp placed between the poles of a magnet. This technique worked so well for substances transparent to the above ultra-violet radiation that even second-order Raman spectra could be obtained.

The second-order spectrum is a thousand times weaker compared to the first-order Raman scattering. The substances investigated included diamond, quartz, rock salt, magnesium oxide, etc. It was this work that set Raman on his new lattice dynamics. After Raman's retirement, Krishnan became Professor of Physics and continued the tradition of Raman spectroscopy with his students and co-workers.

Raman's career at the Indian Institute of Science was not altogether a happy experience for him. His forced resignation from the Directorship and all the unpleasant incidents preceding it made him very bitter. He often expressed his bitterness to visitors. Why did Raman fail miserably? What really happened that led to his resignation from the Directorship? These are questions without any real answers. S. Ramaseshan, a former Director of the IISc, has cited some of the views expressed in this connection: Raman came to the Institute with the idea of making it a centre of science of international standard. What he found was a quiet sleepy place where little work was done by a number of well-paid people.... Raman's speeding up of the entire pace of the Institute was bound to look like criticism of the former management. He made the mistake of not waiting for a year or two before starting actual reforms (Born).

Raman was obviously surrounded by people, both British and Indian, who largely looked upon IISc as a source of sinecure positions. Some of the English faculty resented working under Raman — an Indian — an experience they had never had before. These faculty members had gained the ear of the colonial Government which agreed to put pressure on the Tata family. The Tata representatives on the Council were particularly sensitive to the colonial Government's wishes, as the House of Tatas was very dependent on Government protection. Born has stated: "There is no Indian physicist of the rank of Raman. No man can compare with him in regard to vigour or intensity. This European intensity which Raman exhibited to a marked degree seemed to make many Indians suspicious of him." All changes made by Raman provoked resentment. Many even felt that physics was in the process of becoming a dominant feature of

the Institute. Raman, far too conscious of his own superiority, made other people feel small in his presence. His acute mind and sharp tongue seemed to constantly provoke resentment and tension around him.

All these could have been contributing factors. For one thing, a man of success in India is an object of great envy and he often finds himself in situations full of intrigues and plotting. In fact, Raman's leaving Calcutta appears to have been the result of intrigues and backbiting created by jealous colleagues. The Indian Institute of Science was a much bigger institution even in those times, with a number of scientists and engineers with widely different backgrounds and loyalties. Such being the case, it would have been a difficult task for even a very tactful person to run the place smoothly. Unfortunately, Raman was a person who had no patience, was far from tactful, and did not have much tolerance for different viewpoints. He was easily excitable and said what he thought of people and their actions straight to their faces. Further, his style of administration was highly personalised revealing his strong likes and dislikes. All these qualities made him easy prey and, in less than three years, many, including several senior faculty members, turned against him.

In the matter of the appointment of Max Born to a permanent Chair and in inviting other scientists from abroad, Raman had apparently not taken permission of the management, the Governing Council of the Indian Institute of Science. Some of the other charges levelled against him were that he developed the Physics Department at the expense of other departments, that he wasted money on beautifying the Institute grounds, and so forth.

While Raman could admittedly be a difficult person, there is reason to wonder whether it was not just the 'scientific politics' of the times that brought about his demotion. It is a pity that a scientist of his stature had to suffer indignities which left an indelible bitterness in him. An institution which is governed by consensus and which is bureaucratic by nature was totally at odds with Raman's way of thinking. It is out of this realisation that he decided to create a research institute of his own, where his will and wishes would prevail.

The Raman Research Institute

Raman had visions of a private institute in which he could continue his scientific research after he retired from the Indian Institute of Science. He had planned for this while still a Professor at the IISc, collecting money for such an eventuality. The *Maharaja* of Mysore had earlier gifted for this purpose a lovely piece of land, 11 acres in extent, in one of the prime localities in Bangalore. Raman arranged to build his institute on this land and, by the time he retired from the IISc, in 1948, the building for his new institute was nearing completion.

The Raman Research Institute is situated on a piece of land adjacent to that of Kempegowda tower which defines the northern limit of Bangalore. (The four Kempegowda towers were erected in the 19th century to mark the limits beyond which the city should not be extended without ill-luck descending on it, but in recent years Bangalore has outgrown these limits and has had to contend with congestion, lack of water and pollution.) The land on which Raman built sloped gently towards the north and its soil was lateritic. The Kempegowda tower stands to the southeast on a lateritic hillock and the Sun used to light it up in blazing red. From this tower, you could see the Nandi Hills 30 miles to the north. To the south lay Bangalore, cradled in a shallow valley. The adjoining area in those days was occupied by the beautiful palace gardens and lush agricultural fields. In recent times, the gardens and open fields have given way to housing developments, and the area has become heavily built up.

Raman loved the property, every inch of it was sacred to him. One of the first tasks undertaken by him was to erect a barbed-wire fencing around it. He then implemented an afforestation scheme, planting the barren land with flowering trees, shrubbery, bushes and fast-growing trees for shade and greenery. The first building that was erected was a two-storey one of neatly dressed, light grey granite blocks. The building was essentially designed by Raman with the help of some architects. Raman believed in large rooms with high ceilings and sumptuous ventilation. It was a 'Π' – shaped building

facing the north, the long side laid out in the east-west direction, with the east and west wings at the ends. A protruding portico near the western end served as the main entrance to the building. There were pillared verandahs all round, both on the ground floor and the first floor. A large granite staircase faced the entrance. It had a landing platform at the half-way point, where it turned 180° to lead up to the first floor. These steps were beautifully dressed rectangular slabs of granite cantilevered from the adjacent wall. Raman used to point out this feature to visitors and remark that he could take a full-grown elephant up them to the first floor. The steps had dressed granite banisters.

On reaching the first floor, a pillared porch right on top of the portico invited one's attention. This was a favourite spot of Raman. From this portico there was a panoramic view of the northern side, and on a clear day the distant Nandi Hills could be clearly seen, their well-defined outline resembling that of a reposing bull. Further details on the hills could be seen with the help of a telescope. The foreground was somewhat bereft of vegetation, but the overall picture was of a vista exhilarating to the mind and a feast to the eye. Raman hardly ever failed to give a visitor the experience of this sight, his commentary adding another dimension to the view.

To the west of the building was the majestic tower of the Indian Institute of Science, with the Institute complex in the foreground. This sight however did not please Raman. So he planted a eucalyptus grove to block the view. He never forgot the unpleasant events connected with his tenure as Director of the Indian Institute of Science. These had left a deep scar on him. Sometimes Raman used to make pungent remarks about the Institute. He, however, would quickly change the subject and talk about eucalyptus, saying how much he enjoyed the scent wafted by a favourable wind from that direction.

When Raman shifted his activities in 1949 to the Raman Research Institute, the building was barely completed. There was no electricity and the plumbing was just being laid. In November 1949, I joined Raman as his research assistant. He appointed J. Padmanabhan

as his technical assistant about the same time. A stenotypist was appointed just a little before us. The three of us were the nuclear staff of the Raman Research Institute.

Raman recruited his staff in his own way. He was fed up with rules and regulations followed in big institutions such as the IISc. He applied the criteria of ability and proven merit rather than paper qualifications and evaluated candidates in his own way. Once, there was a query from the Government as to the basis on which he recruited his staff. Raman wrote back saying, "On the basis of proven merit".

The first technical person Raman appointed was Padmanabhan, who was recommended to him by H. Parameswaran. The latter had trained Padmanabhan as an optical technologist. Raman had great regard for Parameswaran who had, at one time, been Professor at Presidency College, Madras, and had later gone to Trivandrum to serve as the Director of Industries in Travancore State. Parameswaran was an expert in optics and had constructed telescopes and other optical apparatus for research in the subject. Padmanabhan had, therefore, received excellent training and turned out to be a master optical technologist. Raman appreciated very much Padmanabhan's work and the excellence he was able to achieve. Padmanabhan had the unique distinction of staying with Raman for twenty years, until the latter's death. He retired from the Raman Institute in 1984, after 35 years of service. Padmanabhan served Raman with dedication; Raman, in turn, liked him very much and treated him very kindly.

In my own case, it was a chance meeting with Raman that resulted in a most happy and productive association with him for eleven years, from November 1949 to October 1960. After obtaining the Bachelor's degree in Science from the University of Madras, I spent a year-and-a-half in search of a business-related career. Not finding satisfaction and drawn towards science by a strong inner urge, I went to the College of Engineering, Guindy, to work as a research scholar in physical chemistry under a well-known physical chemist who headed the Science Department there. After a year, I became a demonstrator with some teaching duties and laboratory work, but

spent my major time in research. My two-year stay at the Engineering College gave me an opportunity for self-education in electrical and mechanical engineering, which stood me in good stead later in my career. Finding that the Engineering College was not an appropriate place for growth as a scientist, I decided to leave and knock on the doors of the Indian Institute of Science, Bangalore, but there was some hitch. However, shortly afterwards, I had to visit Bangalore, to investigate a business opportunity in non-ferrous metals. While there, I made a telephone call to Raman and inquired if I might see him later that afternoon. Luck was on my side; Raman was in good spirits and said "Yes". I went to the Institute and found him taking a walk in the grounds. He welcomed me and talked in general terms about the Institute he was planning to create. In between, he asked me what sort of training I had and then directed some general questions at me. I distinctly remember one of them concerning clouds. He asked what clouds were and why they were visible to the eye. I must have given the right answer, for he said, "You have some common sense". Then he asked me if I knew something about the practical aspects of electrical engineering. He talked to me about plants, flowers and about the origin of colours. I had taken a course in botany and, hence, could respond sensibly.

All this went on for an hour and a half while we took a leisurely stroll. Then he said, "I want an assistant to help me in my research and scientific work, but I have to be careful in selecting the right person". I responded, "Sir if you will give me a chance I will try my best to serve you". Without hesitation, he offered to take me as a Junior Research Assistant, but on one condition, namely that I would have to be on probation for six months; if at the end of that period he was satisfied with my performance, he would confirm me. He jokingly added, "Maybe you will turn out to be like a Faraday to Sir Humphrey Davy". This was a most exhilarating outcome for me and indeed the turning point in my life. Nothing like this had ever happened before or after: a contact with one of the greatest scientists of the century, which was to set me on a course dearer to my heart. In retrospect, all the disappointments I had endured were for the good.

The Raman Research Institute circa *1953.*

This meeting took place on November 1, 1949. Raman immediately dictated a letter of appointment to his typist, signed it and handed it to me, asking me to report for work in ten days' time. He then dropped me at the bus stand. I took the train to Madras that night and, after spending a week in my village home left for Bangalore to start work. Padmanabhan had already joined and so had the other staff member, the typist Balakrishnan. It was from this point that the Raman Institute began functioning.

Raman, meanwhile, went about earnestly building the Institute and its facilities for research. He had bought several microscopes, and there was a roomful of electronic equipment (US military and air force surplus equipment released by DGTD to educational and research institutions from what the American Armed Forces had left behind after World War II). These included magnetrons, microwave generators, oscilloscopes, transmitting equipment, servo systems, aerial cameras, optical systems, infra-red viewers and detectors. A large number of machine tools and lathes, and a liquid nitrogen plant, were also part of this windfall. Radhakrishnan, the younger son of Raman, was an amateur radio expert and had helped in choosing most of the electronic equipment. However, most of the items were not really in working condition, except the optical components and machine tools. Later, a building was built on the western side of the main building for the lathes, machines, tools, glass blowing technology, carpentry and a chemical lab.

Another building called the Spectroscopic Laboratory was built next to the main building on the eastern side.

When it came to buildings, Raman loved to have them built in dressed granite. He also had very definite ideas about their architecture. The main building of the Institute for instance, was almost entirely conceived by him; he had thought out exactly how each room should be utilised. In the main building he provided space for laboratories, library, museums, offices, reading rooms, and bathrooms. His reading room on the first floor, adjacent to the museum hall, was magnificent. It was panelled in teakwood and had teakwood and glass cases for books. There were corner shelves on which were

arranged several spectacular mineral specimens. A large teakwood table with a black glass top stood in the centre of the room, with comfortable cushioned chairs around it. The Kempegowda tower could be seen through the eastern windows of this room and the palace gardens from the southern windows. Altogether this was a lovely room, tastefully decorated, and with books and journals neatly arranged on the shelves. Raman used this room to read, write and sometimes receive visitors. A small adjacent room contained the *Memoirs* of the Institute, all arranged according to number and accessible through a door from the reading room. Downstairs, in the north-east corner, was Raman's private office. This was close to the Institute's administrative office where his stenotypists, clerks and accountants sat. In his private office room, Raman kept his entire personal collection, including memorabilia, medals, diplomas, doctoral gowns, diamonds and other crystals. He would answer telephone calls, dictate letters and transact administrative matters connected with the Institute from this private office.

Before Raman retired from the Indian Institute of Science he visited the United States twice, as a member of the Indian team to the World Bank. Although the official role he played in these two delegations is not clear, he made use of the opportunity to visit several scientific institutions, including the Bell Laboratories at Murray Hill. More importantly, he acquired an exquisite collection of mineral and crystal specimens and gem materials from several dealers in the USA. These had just arrived about the time we joined the Institute and one of the more interesting tasks to befall us was to unpack them.

Raman had a grand plan for crystallographic, mineralogical, gemmological, and geological museums at the Institute and had reserved several rooms on the first floor for this purpose. He immersed himself in the task of designing a suitable display and called in E. K. Govindraj, a well-known photographic dealer and studio owner in Bangalore, to help him. Govindraj, who had a fine artistic sense, suggested the use of teakwood-framed glass cases, with sliding doors and inside lighting, to display the collection. The shelves in the cases

were also to be made of plate-glass. The teakwood casings were to be decorated with a design and fine-polished to bring out the graininess of the wood. Govindraj engaged carpenters, built the shelves at the Institute itself and personally supervised their installation. But he sought Raman's approval at each stage. If Raman did not like anything that Govindraj proposed, he told him so, and Raman's decision prevailed. Govindraj, however, was a very diplomatic and sharp person and he learned very quickly the ways of Raman's thinking.

After the shelves were installed, Raman took great delight in arranging the specimens himself. He used to carry the specimens up to the first floor himself and place them on the shelves. We gave him all possible help. He would have us around him, then try various positions for a specimen and ask each time, "How does it look now?" Thus, considerable time was spent on arriving at the right setting for each specimen, to ensure that it caught the light properly and its beauty was displayed in full measure. These sessions used to last for hours and we greatly enjoyed being with Raman on these occasions, listening to his comments. He did not like labels on the specimens and hence these were removed, but he carried all the information about each specimen in his head. From him, and because we were with him all the time, Padmanabhan and myself learnt the details about most of the specimens, how they were acquired, from which area, and so on.

The most colourful and spectacular crystals were displayed in a corner room with front and side lighting. The larger mineral specimens were exhibited with front lighting in a long room called the Bisseserlal Halwasia Museum. There was a long teakwood case with a glass top and sliding doors in this room and in it were displayed most of the synthetic gems and crystals. In a small room adjacent to the corner room, minerals which exhibited luminescence under ultraviolet (UV) excitation were displayed. The bright green willemite, the red calcites, blue fluorspar and the multicoloured franklinite from New Jersey were part of a spectacular show. They were displayed in a darkened room, but came to life when UV lamps were turned on. Raman loved to show the specimens in white light before turning on

the UV so that visitors could see the contrast. It was like being in a fairyland, where things took shape in splendid colours, as the UV lamps warmed up. Raman would explain to his audience what luminescence is and why the specimens showed such colours. This was one of the main attractions of the museum at the Raman Research Institute and visitors carried away with them a vivid impression of the show. In the western wing, one room was set apart for geological specimens (rocks and rock-forming minerals) and two rooms for the display of butterflies, beetles, stuffed birds, iridescent shells and nacre.

Raman equipped the Institute with beautiful museums, lecture hall, library, offices and laboratories and carried on his scientific work in it with tremendous enthusiasm and fervour. He also took a few research students, but the Institute was founded primarily for him to work on his interests.

Raman had aristocratic tastes. He dreamed of a villa with a sunken garden and a pergola for his residence in the campus of the Raman Research Institute. He again approached the *Maharaja* and asked him to grant him (Raman) four acres of land adjacent to the southern side of the campus. This was part of the agricultural land. His request was granted and he was extremely happy about it. Right-away he fenced the additional property and planted it with a number of flowering trees and shrubs. He then built his dream house, a lovely residence, in the southeast corner of the property. The Director's house was a long one-storey building in dressed granite, facing a sunken garden on the southern side and a pergola on the northern side. The sunken garden was filled with some of the loveliest rose plants in Bangalore. On the eastern side, Bangalore's northern Kempegowda tower stood like a sentinel on the red hill. Raman located his bedroom in such a way that he could see the tower from his bedroom window. For the pergola he chose a violet and yellow flowering creeper. A drive-in portico built of granite stood on this side straddling a circular driveway. On the western side, Raman planted a variety of flowering shrubs and laid out several walks. All in all, it was a lovely location and a beautiful home.

Raman did not occupy the house right away and continued to live in his bungalow in Malleswaram, about two miles from the Institute. The first occupant of the Director's quarters was Palmer Craig, a visiting professor of electrical communications from the USA to the Indian Institute of Science. This curious occurrence happened this way. Craig was looking for a house when he met Raman casually one day and mentioned his predicament. Jokingly Raman said, "I have a lovely house, but I don't think you will pay the kind of rent I want for it". Craig wanted to know how much the rent was and Raman quoted Rs 2000 a month. Craig saw the house and immediately agreed to pay the rent asked. To an American Professor this was nothing very extravagant and, in any case, it was a lovely location and a well-appointed bungalow. Raman was caught in a tight corner, but agreed to let the house to Craig for two years. Maybe he thought it would bring in a tidy sum of money which he could use for the Institute. But towards the end of the contract, he was getting impatient, for he wanted to move into the house very badly. Once or twice he remarked to me that he had made a mistake in letting the house and that he should not have succumbed to the high rent.

Raman had arranged to build a hostel and two houses in the campus and wanted me to occupy one of the houses. In fact, he wanted me to design a compact building with all amenities and took a great interest in the project. He used to remark: "You must live in comfort. Have a nice Western toilet and a geyser in the bathroom." He was very considerate to me and gave me the house free of rent. Living in the campus had advantages as far as scientific work was concerned, but in those days the Raman Institute campus seemed so far away from civilisation. The air, however, was pure and the surroundings lovely. The research students, my family and the family of Venkatachar, the manager of the Indian Academy of Sciences, lived in these quarters as one large family, sharing the troubles and enjoying the amenities.

Before Raman moved into the Director's house at the Raman Institute campus, he lived in his own palatial house in the Malleswaram section of Bangalore. This house was known as *Panchavati*

(Hermitage), appropriate indeed for his name, and had extensive grounds with neem, mango, jack and other trees. It was an old house which Raman had bought for a bargain price. The story goes that the house had the reputation of being haunted and hence did not attract buyers. When Raman was considering buying the house, he heard the story and, apparently, remarked that he was a greater ghost than the resident one and would soon drive it out.

Eight miles west of Bangalore, Raman had a lovely estate of about 100 acres near a village called Kengeri. The estate had a nice bungalow in it and consisted of agricultural land as well as extensive groves of trees. A stream ran along its southwestern perimeter. Raman used this property mainly for weekend recreation. He loved to walk there. Usually he left the Institute on Saturday afternoons and reached the estate before sunset. He would then walk to a particular point in the estate and watch the sunset. Lady Raman accompanied him on these trips to Kengeri and attended to his needs. The bungalow was fully equipped and furnished. There were workers to take care of the agricultural operations and maintain the property. Lady Raman managed the servants and raised vegetables and other crops. On Sunday mornings, Raman would take a long walk, enjoying the scenery. After lunch and some rest, he and Lady Raman would return to Bangalore in the late afternoon. Raman wanted to locate a centre for astronomical research in this estate.

In the late Fifties, Raman got about five acres of land adjacent to the Institute property on its eastern side. The City Improvement Trust Board of the Government of Karnataka, which had by then taken over most of the land belonging to the *Maharaja*, allotted this land to the Institute — but at a price; Raman paid about Rs 300,000 for it. This land was part of the lateritic hill sloping towards the main road, on the northern side of the Kempegowda tower.

Raman had ideas of putting up additional buildings on this property as part of his expansion plans for the Institute. He actually arranged to have the foundations laid for a building to house a new library. Raman thought that the City Improvement Trust would claim back the land if it was left unbuilt. In the Seventies, long after his

death, several new buildings were indeed put up on this land, including a building which houses an impressive radio telescope for millimetre wave radio astronomy. Raman's foresight and vision have proved absolutely correct. The value of the land has multiplied by a factor of two or three hundred at current prices and had Raman not acquired this land, it would have been impossible for the Institute to expand one of its principal activities in such a convenient location.

Raman also acquired a few acres of land in Madras, in a locality which became one of the nicest residential sections in the city. He put up a house there and wanted to establish a branch of the Raman Institute in Madras devoted to mathematical sciences. This property was, however, sold by him in the Sixties for over a million rupees.

Early Days

For nearly two years after my joining, that is until the end of 1951, the Raman Research Institute did not have any electricity. We set up a dark room for photography, and darkened the end room in the west wing to carry out optical studies with sunlight. A pillar with a platform was built at a suitable distance outside this room on the southern side and sunlight was reflected with a hand-operated heliostat. A heliostat is a device used to reflect a beam of sunlight at a constant angle and consists of a mirror mounted on an axis which points at the Pole Star. It follows the sun and throws the reflected light beam on the same spot. The device is usually driven by a clock mechanism, but in the early days of the Institute we used the human hand to operate our heliostat. One of the laboratory attendants was stationed outside and he rotated the mirror axis as smoothly as possible to keep in step with the sun's motion. This was a tedious job and, at times, the beam disappeared when the attendant dozed off. At other times, the beam was kept in order with a knock on the window to give the necessary feedback. Sometimes there was a constant struggle between the experimenter and the attendant. Amazingly, it all worked satisfactorily and we got a lot of research accomplished this way, despite the handicap of not having electricity.

Raman was a great believer in the efficacy of sunlight for light-scattering experiments, for it was this technique that provided him the first clues to the Raman scattering process. Therefore, the lack of electricity did not deter Raman from carrying out first-class experiments. Some very fine studies were performed on the optical phenomena exhibited by iridescent feldspars, *viz.* labradorite, moonstones and opals. Filtered sunlight, using a Wood's glass filter, proved to be excellent for exciting the fluorescence of diamond, and in particular to photograph the luminescence patterns exhibited by diamond cleavage plates. We used to sit for hours in a darkened room, with a beam of sunlight, to probe the optical phenomena exhibited by gems, and come out with illuminating findings.

Whether it was the luminescence of diamonds, the multicoloured spectrum of opal, the labradorescence of feldspars, or the Schiller effect in moonstones, Raman's wonder and amazement knew no bounds. Raman thought aloud when making observations and it was an unforgettable experience to listen to him. The scene at such times would be something like this:

He would be looking at a sample with the sunlight shining on it and remark: "I say, you won't believe what I see. It is a beautiful effect." Then, after a while, he would say, "I think I see it, but you know it comes and goes". The standard response of the bystander would be "Yes, sir". His next statement, after a few more observations, would be: "I don't think I was right in thinking that way. Now I don't see it. I think I was very foolish to have mistaken that spurious effect as the real one." It would then be awkward for the bystander to say "Yes", in case Raman was offended by the confirming "Yes". However, he need not have worried because Raman was only thinking aloud and usually what a bystander said was irrelevant to him at such times. He only wanted the onlooker to share his own excitement.

In 1950, Raman recruited seven research scholars, T. K. Srinivasan, a geologist with an M.Sc. in geology from Mysore University, K. S. Viswanathan with a Master's degree in mathematics from

Madras University, D. Krishnamurti with a B.Sc. (Hons.) degree in physics, also from Madras University, S. Chandrasekhar with an M.Sc. in physics from Nagpur, A. K. Ramdas and M. R. Bhat with B.Sc. (Hons.) in physics from Poona University and S. Venkateswaran with a B.Sc. (Hons.) in physics from Madras University and a professional certificate in communication engineering. S. Pancharatnam joined in 1954; he had taken an M.Sc. in physics from Nagpur. The Council of Scientific and Industrial Research of the Governament of India also granted several senior and junior research scholarships and some research scholars were appointed on these.

Raman wanted a geologist because of his interest in the physics of minerals. Srinivasan was sent on several expeditions to collect rocks and minerals and, as a result, the geological collection at the Institute grew rapidly. Raman asked Srinivasan to work on the optical properties of minerals and then on the magnetic properties of rocks, but Srinivasan's studies never took off the ground. Somewhat disheartened, he left the Institute after three years to take up a job with the Associated Cement Company as a geologist. Venkateswaran also left after a brief stay.

In general, the scholars who were experimentally inclined became very dispirited because there was no electricity for two years and they could not carry out any experimental studies. Those who took to theoretical studies, like Viswanathan and Chandrasekhar, were active in research. Because of this situation, the research scholars were asked to attend the theoretical physics lectures given by B. S. Madhava Rao and K. Subbaramiah at Central College, Bangalore. Krishnamurti was assigned to a theoretical problem, to calculate the elastic constants of diamond from its vibrational spectrum, and he made a success of it. Chandrasekhar took to theoretical formulation of the optical activity in crystals, while Viswanathan went into lattice dynamical theories. Although the lecture programmes gave a good theoretical grounding, lack of experimental contact had a deleterious effect on the experimentally inclined scholars. The only experimental research programme was the personal programme of Raman in which I had an active role assisting him. Srinivasan joined

in one project, namely the study of moonstones, and subsequently co-authored one of the papers.

Towards the end of 1951 the electrification of the Institute was completed and I had a major role to play in it. The day electricity was switched on from the main power line there was jubilation among everyone. Raman was particularly pleased. One of the first things he did was to run upstairs, switch on the ultra-violet lamp in the luminescent mineral room and enjoy the spectacular display of the fluorescent colours. By the end of 1952 we had spectrometers, X-ray units, and a workshop with full-fledged mechanics. I set up most of this equipment and X-ray diffraction studies were now entrusted to me completely.

As various facilities were added, Raman recruited technicians, machinists, carpenters and a librarian to man them. He was very particular to recruit a book-binder to ensure that journals received in the Library were bound attractively in leather, with their titles printed in gold. Most of the technical people he recruited stayed on at the Institute and made it their career. Among them, a young glass-blower by name Balakrishnan, who joined the Institute around 1952, was particularly well liked by Raman, for he turned out to be a person with all-round skills. He was an expert glass-blower, but could also operate a wide variety of electrical and electronic instruments. Raman valued ability and skill and spontaneously appreciated good and efficient work.

Raman was very prompt in his correspondence, being quite business-like. If a letter needed reply, he would send back one right away. Decisions were taken by him quickly and he was easily accessible to everyone. There were no formalities and you did not have to go through a secretary. Even the gardener could go in and talk to him. In fact, the gardener received special treatment. Any matter connected with trees or shrubs received Raman's immediate and personal attention.

Raman had a driver by name Parthasarathy who had been with him for a long time. He was quite a character, but was a good and careful driver. Raman had absolute trust in Parthasarathy and would

believe whatever he had to say about the car, its health and its performance. Parthasarathy was also Raman's time-keeper. Raman had many wrist watches, but he either forgot to wear them, or even if he had one on his wrist it would not be showing the proper time, for he would not have wound it. Driver Parthasarathy had an old wrist watch, perhaps a quarter-century old, with only the hour hand on it. Raman always asked him what the time was before he started on an outing. And Parthasarathy would quite correctly estimate the time from the position of the hour hand and announce it. Then the command would come from Raman: "Let us go. It is getting late." Raman had an old Willys sedan of light grey colour which gave excellent service. In 1951, or thereabouts, he bought a new Studebaker, a large car two-tone in colour, grey and green.

Raman was an early riser and was always ready for work at 6 a.m. or even earlier. Some days he used to walk the two miles to the Institute early in the morning, cutting across Malleswaram and taking the short cut through Sankey Tank Road. Lady Raman would later send the car with his breakfast, usually a piece of toast, banana and coffee. One day, Raman told us that he would like to become independent of the driver. So he bought a new bicycle. For two days, Raman, Padmanabhan and myself used to ride our bicycles to the Institute. This, however, did not work out, for Raman became very tired pedalling the bicycle up the gradient, all the way from the Institute of Science Circle to Hebbal. Further, Raman did not pay much attention to traffic on the road and often strayed to the wrong side. This proved dangerous and Lady Raman forbade him from cycling to the Institute. He then gave his cycle to Padmanabhan. It was strange the way Raman would get on his bicycle. He would put one foot on the fork and climb on, take a few hops with the other foot and then settle on the seat. I presume that is the old way of doing it, but it was amusing to watch a 61-year-old Nobel Prize-winning scientist hopping on to his bicycle seat in this fashion, before riding alongside two of his assistants. Raman, however, did not usually pay much attention to what others might say.

There was another occasion when he hurt his toe and could not wear shoes. For nearly a month he went about his business barefooted. He would of course be fully dressed, but there would be no shoes on his feet! It was funny to watch Raman walking barefoot, unmindful of what others might think of him.

On the first of every month it was almost a religious duty with him to go to the Central Bank of India in the city and return with crisp new currency notes for the disbursement of salaries. If he was ill and could not go, either Lady Raman went or he would ask me to go. He loved to see the salaries paid promptly on the first of every month and the employees kept happy and satisfied.

Raman instantly appreciated a job well done, whether it was scientific research, technical work or any other kind of activity. Padmanabhan used to make glass and quartz spheres of various sizes for Raman and had evolved a clever technique to make them. They came out beautifully. There is a magical quality to a large sphere of quartz; they are fascinating to look at. Raman used to go into raptures whenever Padmanabhan finished a sphere and placed it in his hands. He would look at it and say: "Oh, is it not lovely? Padmanabhan, this is beautiful! This is fantastic!" He would place the quartz sphere between crossed polarisers and admire the concentric coloured rings that appeared when viewed along the C-axis of the quartz crystal.

Balakrishnan had a lovely hand and Raman often asked him to draw on the blackboard, using coloured chalk, pictures and equations for his lectures. In those days, there were no Vugraph machines, but Raman invented his own Vugraph by having the relevant things drawn beautifully on the board. Raman appreciated Balakrishnan's artistic work on the blackboard very much and used to shower praise on him. Such was his nature.

The colours of minerals, gemstones and crystals

Raman was deeply interested in the colours exhibited by rocks, minerals and crystals. He carried out several important investigations on them, in which some of us collaborated. He was proud of the fact that his museum collection served as the source material for this research.

He told visitors: "I collect these items not just for display. They are the source material for my research." He had a lovely collection of what are known as iridescent feldspars, which are naturally occurring silicate minerals that exhibit very colourful optical effects. Raman was deeply attracted by these feldspars known in mineralogical literature as labradorite, peresterite, murchisonite, amazonite, moonstone and sunstone.

While the labradorite and peresterite specimens were large, with flat, polished surfaces, the moonstone, murchisonite and sunstone were cut and polished as cabochons or hemispheres. There were also uncut crystals of these in the collection, with crystallographic cleavages. Among these, the iridescence of labradorite is most spectacular; it is in the nature of a brilliantly coloured metallic reflection coming from the depth of the crystal when the specimen is held properly, with respect to the incident light, and viewed. Further, the dark background of the labradorite accentuates the colours, which change hue when the angle of observation and incidence of light are changed by tilting the specimen. A properly sectioned and polished specimen of labradorite is gorgeous to look at and immediately arrests the viewer's attention.

The optical phenomenon exhibited by moonstone is in the nature of a diffuse reflection and the colour varies from a deep blue to bluish-white to a silvery-white sheen. Most of the gem-quality moonstones originate from Ceylon (Sri Lanka) or Korea and the blue diffusion observed in them is sky blue in colour. There were some very fine specimens of Ceylon and Korean moonstones in Raman's collection.

One of the very first research projects undertaken by Raman at the Raman Research Institute was the study of iridescent feldspars, in which I assisted him. As remarked earlier, there was no electricity in the Institute at the time, so Raman used sunlight to study the optical phenomena. In fact, this proved to be the best way, for a narrow beam of sunlight incident upon the surface of a sample immersed in a suitable fluid medium revealed rich details of the optical effect exhibited by the stone. Thus, if the optical effect was in the nature of

a reflection, coloured reflections were observed on a white card held at the appropriate distance from the sample surface. In the case of moonstone, a diffuse reflection was observed spreading out into an elliptic halo, blue or whitish in colour, depending on the moonstone. In the case of sunstone, a golden-coloured halo appeared on the white card.

All these details gave clues about the optical effect in question and, with Raman's intuitive understanding of optical phenomena, scattering of light and diffraction effects, the underlying cause of the observed effects crystallised. For us it was the greatest opportunity to learn physics, sitting with Raman during an experimental observation session. We obtained an intuitive understanding of optical principles just listening to his comments during these experiments. Such fast understanding could not have come from searching a dozen books.

From all these studies it became clear that the optical effects exhibited by iridescent feldspars in general originated from the optical heterogeneities in the mineral. The size and shape of the heterogeneity determined the character of the optical effect. Thus, in labradorite, the brilliant iridescent colours were due to the presence of one of the component feldspars in the form of thin lamellae inside the specimen, distributed more or less uniformly over large areas. Because of the differences in the refractive properties between the lamellae and the matrix feldspar, the light was diffracted or reflected from inside the matrix crystal, the colours depending on the thickness of the lamellae, the angle of incidence, and the reflection of the light. Detailed optical studies on moonstones revealed that the blue or silvery diffuse reflections were because of the presence of the finely segregated component feldspar (soda feldspar) with dimensions close to the wavelength of light inside the moonstone. Further, these segregations, or the optical heterogeneity, had a cigar-like shape, all arranged more or less in parallel orientation in the matrix crystal of potash feldspar.

Raman got interested in opal, a well-known, naturally occurring form of silica. The so-called precious opals are highly valued as a gemstone. He had a fine collection of opals originating from Australia, Hungary and Mexico. Some of them were beautiful specimens. A very detailed study of the optical characteristics of the reflections were made along with some X-ray structural studies. From these, the conclusion was drawn that opaline material was basically amorphous and possessed two different types of local structure, namely cristobalite-like and quartz-like. The studies suggested that the difference in refractive index gave rise to the optical heterogeneity. However, a more recent electron microscopic study of the reflecting lamellae in opals has shown that there is a periodic structure in them, with regularly spaced air inclusions in the opaline matter, which are believed to be the cause of the bright-coloured reflections emanating from the stones. Opals have recently been made synthetically and these are known as 'Slochum stones'.

Raman conducted extensive optical studies on pearls, amethysts, iridescent agate, jade and several other forms of silica. In each case, it was the colour or the optical effect that attracted his attention and he had novel explanations for every effect. Two other systems in which Raman got very interested were iridescent potassium chlorate and calcite. Krishnamurti was involved in the study of iridescent potassium chlorate and obtained some beautiful spectra of the monochromatic reflections from potassium chlorate crystals. The iridescence of potassium chlorate is an optical effect arising out of multiple twinning of the crystal on a fine scale, repeated with amazing precision. When white light is incident on such a twinned crystal, brilliant monochromatic reflections are observed. The reflection is analogous to a Bragg reflection of an X-ray beam by a crystal lattice. In the case of potassium chlorate, the spacings are of the order of a wavelength of light and, hence, give rise to Bragg-like reflection of the light. Krishnamurti studied this phenomenon in great detail. Raman and Krishnamurti published a series of perceptive papers elucidating the origin of the effect.

Another beautiful optical study, in which Ramdas collaborated with Raman, concerned iridescence in calcite. In calcite, the iridescent colour was again shown to be due to twinning, but in this case even a simple twinning gave rise to a bright-coloured reflection at the twin boundary. This was shown to be due to the large magnitude of the difference in refraction and dispersion associated with the twin members.

All these studies were published in the *Proceedings of the Indian Academy of Sciences* and Raman had them reprinted under the title *Memoirs of the Raman Research Institute*. Raman spent considerable time in writing his papers and paid great attention to English, grammar and style. He often used Latin terms in his papers to make a point more emphatic. Papers written by Raman were like a piece of literature, a delight to read.

Raman immensely enjoyed his investigations on gems and minerals. This body of work reflected Raman's taste for aesthetics in physics. He loved to demonstrate his findings to visitors and he would explain to them in simple language some of the more esoteric optical phenomena. *Maharaja*, prime ministers, politicians, officials, students and laymen all came to visit the Institute and see Raman. They went away enthralled as much by his vast collection of gems and minerals as his inspiring tales.

Love of diamonds

Raman's love of diamonds is well known. Describing diamond as the 'king of solids', he carried out extensive studies on it. The first light-scattering measurement on diamond was initiated by Raman and he assigned the task to his brother, C. Ramaswamy. The story goes that when Ramaswamy got married, just prior to joining Raman in Calcutta to work with him, his father-in-law had presented him with a diamond ring, as was customary in those days. When Raman noticed the stone, he was apparently fascinated by its sparkle and clarity and suggested that Ramaswamy record the spectrum of the scattered light from that very diamond. In this study, the strong vibrational line characteristic of the diamond lattice was recorded for the first time.

It was also discovered that the diamond exhibited a blue fluorescence when excited with ultra-violet light. A scientific paper was written on this phenomenon and, thus, diamond entered Raman's life.

Raman had a collection of about 600 diamonds of different kinds and origins. These were from various sources, sometimes received as gifts and sometimes bought. He used them all in his studies, classified them according to their properties and boxed them beautifully. He gave special names to them and had a fund of stories about each.

Raman was decorated by the *Maharaja* of Mysore with a pendant studded with 63 diamonds at the time (1935) he was honoured with the title *Rajasabhabhushana*. This beautiful piece of jewellery promptly entered scientific literature, for Raman studied the luminescence characteristics of the diamonds set in the pendant and drew several interesting conclusions about the nature and intensity of luminescence exhibited by diamonds when excited by ultra-violet light. Raman and his collaborators took to the study of diamonds intensively in the Forties; they published a series of articles on the subject in the *Proceedings of the Indian Academy of Sciences*.

The diamond collection was kept under lock and key, being shown only to chosen visitors. A fortunate few saw the splendid luminescence of some of his brilliant fluorescing diamonds, a phenomenon best seen with a beam of condensed and filtered sunlight in a darkened room. The filter was made of Wood's glass, which excluded the visible rays and admitted only the ultra-violet. The tabular diamond Raman had christened as 'my Kohinoor' exhibited a brilliant blue fluorescence, almost lighting up the room when placed in the filtered and condensed beam of sunlight. Another gem-cut diamond named 'green diamond' shone with a dazzling green colour when thus illuminated. There were other stones in the collection as well, whose luminescence varied from bluish white to red, with intermediate colours along the line. When these diamonds came to life with their brilliant fluorescence, Raman's eyes would light up and his expression "Isn't it beautiful?" was contagious. Anyone who saw this display could never forget either the diamonds or Raman's way of communicating the aesthetic experience.

In the early days at the Raman Institute, Raman used to impress visitors by showing them the luminescence in diamond and explaining to them how diamonds should be tested before buying. The so called 'blue jaggers' were the favoured type in the Indian jewellery market. In strong white light, a 'blue jagger' shows a light bluishness in its body, apart from the usual fire and brilliance of the diamond. This blueness actually comes from the blue luminescence of the diamond. A 'blue jagger' under ultraviolet light exhibits a strong blue luminescence; this is a simple test to make. Further, diamonds can have minute defects which are only observable under a magnifying lens or a microscope. There can be black spots due to graphitic carbon, or fine cracks. The presence of these defects reduces the value of the diamond. Similarly, the body colour can vary from pure white to yellow to green to brown, and black in the worst case.

Anyone buying a diamond should watch for the three C's as the trade calls it: colour, clarity and cut. A gem diamond should be examined at least with a 10x lens for black spots and cracks inside, and for fracture and quality of the cut outside. With the proliferation of simulated diamonds, a very quick test for diamond would be to take the Raman spectrum with a laser. A real diamond shows a characteristic Raman line at 1332 cm^{-1} displaced from the laser line. Such a test can be made in a matter of minutes with modern instrumentation.

Now and then, someone would come to the Raman Institute carrying a bag with a stone in it, believing it was diamond. Raman could tell by inspection whether it was diamond or not, but he always tested for luminescence, to be certain. Sometimes he would test the material for hardness and birefringence, the latter with crossed polarisers. The stone invariably would turn out to be a lump of quartz at best, to the utter diappointment of the seeker after riches. Others used to seek Raman's advice before buying diamonds for earrings, pendants or other jewellery. In the early days, Raman would amuse himself by looking at them if he was in a good mood, and the visitor was known to him or Lady Raman. In later days, he used to delegate this task to me or to Padmanabhan. After I left the Institute, Padmanabhan turned his expertise into a small but lucrative side-business.

Raman's collection also included a large number of plates which are called 'mackels' in the diamond trade. 'Mackels' can be bought in sizes ranging from a few millimetres in linear dimensions, and 1 to 2 mm in thickness. These are natural cleavage plates. Although diamond is a very hard substance, in fact the hardest substance known to science, it can be cleaved very easily with a sharp knife-edge by the experienced cutter. To achieve this, the diamond has to be held suitably, with the knife-edge positioned along the proper crystallographic direction, usually along the so-called octahedral plane. If everything is right, a sharp knock on the knife will split the diamond perfectly along the desired direction. Diamond is so hard that only diamond can be used to grind or polish diamond. Diamond-cutting, shaping, grinding and polishing is an old art, but modern technology has brought some innovations into the trade.

These cleavage plates were very useful for certain types of study, particularly for observing the perfection and the state of strain in them. The majority of cleavage plates exhibit luminescence patterns when illuminated by UV light, which is to say that the luminescent areas are not uniform but showed geometric patterns. Filtered sunlight is one of the most effective ways of revealing these patterns and for photographing them. I have photographed scores of these luminescence patterns for Raman. These plates also exhibit what is known as birefringence patterns when examined between crossed polarisers. These patterns bear a strong resemblance to the luminescence patterns. Evidently the two have a common origin and Raman held the view that they were connected with the fundamental structural properties of the diamond.

Raman was well aware that India was the original home of some of the best-known diamonds in the world, several of which had found their way to other parts of the world from India and helped to spread the fame of this gemstone. He had in his collection a number of diamonds collected from Panna in what is now the state of Madhya Pradesh. Writing about the Panna diamonds in his collection, he said:

"At the present time, diamonds are still forthcoming at and near Panna in Central India. Two visits to Panna made by the author many years ago gave him the opportunity of inspecting numerous specimens of the diamonds found in that area in their original form as crystals. Particular mention should be made of the magnificent set of 52 uncut diamonds ranging in size from 25 carats down to 2 carats strung together into a necklace by a predecessor of the Maharajah of Panna. The beauty of the necklace arises from the lustre and shapeliness of the gemstones. The two visits to Panna also enabled the author to acquire for his collection a set of specimens for a more detailed study.

The external features exhibited by the Panna diamonds in the collection are highly instructive. They are of very varied sizes and shapes. Two of them present a close resemblance to octahedra in their general shape. But the octahedral edges are not seen and indeed there is not the slightest indication of their presence. On the other hand, the edges along which the diagonal planes of symmetry meet the curved surface of the diamond are conspicuously visible. The six points where these planes intersect in pairs are located at the six vertices of the pseudo-octahedral form of the crystal, while the eight points at each of which three planes intersect appear at the centres of its eight curved faces. These features indicate that while the diamond has the inner symmetry of the tetrahedral class, its external form which mimics octahedral symmetry is the result of the interpenetration of oppositely directed tetrahedral forms within the diamond.

In some of the Panna diamonds, the lower or tetrahedral symmetry is much more obviously exhibited in the externally observed forms of the diamond than in others. There are also several specimens in which the external shape of the diamond resembles neither an octahedron nor a tetrahedron but is almost spherical in form. But in all cases the curved surfaces clearly exhibit the ridges where they are intersected by the six diagonal planes of symmetry of the tetrahedron."

The physics of diamond

Raman had a passionate interest in the physics of diamond and came back to the subject several times during his lifetime. First he was interested in understanding its vibrational spectrum, which led him to formulate his theory of lattice dynamics. Then he proposed that there existed two forms of diamonds, a theory he based on certain characteristic properties diamonds showed. From a study of the diffraction of X-rays by diamond, Raman proposed a new kind of X-ray reflection which he chose to call 'quantum X-ray reflections'. He filled the *Proceedings of the Indian Academy of Sciences* with his memoirs.

According to Raman, carbon atoms, which have *s-p* bonding, form a crystalline solid in diamond with tetrahedral symmetry (Td). This form, lacking in centre of inversion, is ultra-violet- and infra-red-absorbing, blue luminescent, etc. The other form of diamond has full octahedral symmetry (Oh) and is ultra-violet- and infra-red-transparent and is usually nonluminescent. Raman described the birefringence and luminescence patterns, X-ray topographs and other properties of diamond in terms of these two forms of diamonds. He proposed that these properties owed their origin to the interpenetration of the two forms.

Although these ideas appeared to be consistent, some crucial experiments around 1958 established that the difference in the physical properties of diamond were correlated with the presence of nitrogen as a substitutional impurity in diamonds and had nothing to do with its fundamental character. Diamond crystallises only in one form, namely (Oh) symmetry, having the full symmetry of the cubic system. Further, the non-Bragg X-ray reflections exhibited by certain diamonds, which Raman believed originated from the interaction of the lattice vibration with the Bragg planes, were precisely those with nitrogen impurities, the nitrogens having formed platelets, which gave rise to non-Bragg spots.

'The Physiology of Vision'

In the Sixties, Raman got very interested in the physiology of vision. He educated himself very thoroughly on the anatomy and physiology

of the eye and how it functioned as the visual apparatus *par excellence*. He used to talk to visitors about rod vision, cone vision, colour blindness and acuity of vision. He carried out very simple experiments with colour filters, using himself and others as guinea pigs. The culmination of this work was the publication of a treatise entitled *The Physiology of Vision*.

Raman came to the conclusion, as stated in his own words, that there is no reason to believe that the ideas regarding the nature of vision and of visual processes inherited from the 19th century would be sustainable at the present time, either on theoretical grounds or even as purely empirical descriptions or interpretations of the observed phenomena. This conclusion was based on many observations he made in regard to matters like the colours exhibited by natural objects such as the night sky, the foliage and flowers, the birds and butterflies, and so on. His book has the stated purpose of setting out in a systematic manner the procedures he adopted and the results he obtained in carrying out several experiments relating to vision and colour. He wrote that his was an independent study without being influenced by ideas and beliefs inherited from the past. He used to remark, half jokingly and half seriously, "I may get another Nobel Prize for this work". The topic was indeed very interesting and timely and, in fact, a Nobel Prize was shared by Ragnar Granit, Keffer Hartline and George Wald in 1967 for their discoveries concerning the primary physiological and chemical visual processes in the eye.

It is interesting to note that the topics dealt with in the book are as diverse as flowers, gemstones, and the structure and functioning of the retina. While writing about flowers, Raman talks of asters, orchids, roses and so on. While writing about gemstones, he talks of emeralds, the red rubies of Burma, and the blue sapphires of Ceylon. While writing about the retina, he describes his own technique and methods of observation which enable us to view the living retina and thereby gain some understanding of its structure and functioning. These are topics which unquestionably cover a very wide range and give us some insight into Raman's interests and into his thinking in

the last years of his life. In fact, during the years when he was working on problems of vision, he used to lead many of his visitors into a darkened room, telling them with enthusiasm that he would let each one see his own retina, by adopting a novel procedure discovered by Raman himself. The following is a description of this procedure:

> "The technique employed is the use of a colour filter which freely transmits light over the entire range of the visible spectrum except over a limited and well-defined region which it completely absorbs. With suitable dye-stuffs in appropriate concentrations it is possible to prepare colour filters of gelatine films on glass, exhibiting the spectroscopic behaviour described. Holding such a colour filter before his eye, the observer views a brilliantly illuminated screen for a brief interval of time and then suddenly removes the filter while continuing to view the screen with his attention fixed at a particular point on it. He then observes on the screen a picture in colours, which is the chromatic response of the retina to the light of the colour previously absorbed by the filter and which impinges on it when the filter is removed. Actually, as will become clearer presently, what the observer sees is a highly enlarged view of his own retina projected on the screen and displaying the response of the retina in its different areas produced by the incidence of the light of the selected wavelengths. By using a whole series of colour filters whose characteristic absorptions range from one end of the visible spectrum to the other, we are enabled to explore the behaviour of the retina over an extensive region under excitation by light of different wave-lengths which in the aggregate cover the entire visible spectrum."

His observations on a few other topics dealt with in this treatise, such as the dyes used in textiles and night-blindness, are quite original. In fact, the treatise is a remarkable piece of work in that it presents a new approach to the whole subject of the physiology of vision.

Butterflies

The museum of the Raman Research Institute contains a beautiful collection of beetles and butterflies. Raman was fascinated with the colours of these insects, the most colourful of which were the butterflies called Morpho Brazilius and certain Himalayan varieties. These large-winged butterflies, exhibiting a beautiful blue iridescent colour, are spectacular when their wings are spread out.

The origin of the colour in beetles and butterflies interested Raman and he wrote a paper on the subject, showing that a regular periodic structure in their wings produced the beautiful colours, due to the diffraction of light. The colour depended upon the angle of observation and was a brilliant metallic blue or bluish-green.

In the world of butterflies, the wings getting their colour due to the absorption of light by pigments is more common. Pigments selectively absorb certain colours from the white light and this endows the specimen with the complementary colour. Thus, red colour results whenever green and blue are strongly absorbed.

Raman was also fascinated with colours due to pigments in butterflies, and wanted to enlarge his collection by adding these species of butterflies. Man of action that he was, he resorted to catching butterflies. For this purpose, he would go to his country estate in Kengeri and there, with a net bag attached to a long pole, he would run after the butterflies as they flitted from one branch to another. Bagging them is quite an easy operation, but for a 65-year-old person to run after butterflies and bag them is something unusual, at least in India. Raman was perhaps the only Nobel Prize-winning physicist who chased butterflies! He carried out this operation with great enthusiasm for several weeks, often assisted by Padmanabhan. It seems to have amused Lady Raman very much, for she often jested about her husband running after butterflies. The specimens were put in a jar and brought to the Institute where Padmanabhan treated them and mounted them in glass cases, as directed by Raman.

Raman and the bees

Since the Raman Research Institute is situated on a hillock and, in the old days, was surrounded by agricultural land, the palace orchard and the palace gardens, it was a haven for honey bees. You could find beehives on the eastern side of the building, beneath the roof hanging. Such beehives are to be seen even today on the tower of the Indian Institute of Science. These were wild bees, deadly when provoked.

To the east of the main building, Raman had built his Spectroscopic Laboratory. This was a stone building with a high roof and had a dome structure built on it for a telescope. It was Raman's idea to have an astronomical telescope, for he also had a strong interest in astronomy. No telescope was installed there during Raman's time. A back entrance and a staircase provided access to the domed part of the building. The domed structure also had a door which opened out onto an open terrace which was actually the roof of the Spectroscopic Laboratory. The beehives on the main building roof were at the same level as this open terrace and only a short distance away.

One day, Raman was taking round an American visitor who had been brought to the Institute by a Mr Venkateswaran who was the head of Associated Cements in Bangalore and known to Raman. The three of them climbed to the open terrace above the Spectroscopic Laboratory and Raman was apparently pointing out the beehives some 100 ft away when, suddenly, a swarm of bees began to attack the party. They ran through the door leading to the stairs, but, in the confusion, did not close the door behind them. The angry bees pursued them and delivered their stings without mercy. The American gentleman, in confusion and pain, must have shaken his arm so violently, an expensive Rolex gold watch flew from his wrist somewhere along the route. The three of them, including Raman, kept running for their lives, shrieking and uttering cries of pain, while the bees continued to swarm around them. Venkateswaran sought protection in the parked car near the portico and shut himself in. The servants of the Institute, who witnessed the spectacle, ran for their

lives as the bees began to attack everyone around. A few of those attacked ran to the water storage tanks located in the garden and submerged themselves in the water to avoid the bees.

At the time, I was in the photographic dark room developing some negatives. Raman sought refuge there, entering the room turbanless and crying in pain. Evidently he had lost his turban in the commotion and this only made matters worse, for the bees venomously attacked his head. However, the bees left Raman alone once he entered the dark room, for they could not see in the dark. But when I went out momentarily, I was stung a few times; it was only then that I realised what had happened. After a brief rest in the dark room, I took Raman to another large room for fresh air. Seating him in a comfortable chair, I examined him. I pulled out half a dozen bees from his ears with a forceps and several stings from his head, face and hands. Raman was exhausted; he was panting breathlessly and perspiring profusely. I gave him some water, rested him and then had him taken home.

As for the American gentleman, the attack was a disaster for him. Every exposed part of his body had swelled up and turned black and blue.. He fell unconscious on the lawn and had to be hospitalised. Venkateswaran, meanwhile, took off in the car and disappeared from the scene for a while. The next day, Raman was back to normal and came to the Institute declaring, "The bee bite has made me stronger". He was then about 66 or close to it, and it is amazing how quickly he recovered. He had a robust constitution and was tough.

After this incident, Raman declared war on the bees and forthwith ordered their extermination. Padmanabhan was put in charge of this operation and he used chemicals and fire to destroy the beehives. The bees, however, were persistent and returned to the same place after some time. But Padmanabhan took necessary steps again to deal with them. It was a continuous battle.

Back to the starting point

In the course of the 1950s, all the students who had worked with Raman obtained their Doctorates. Chandrasekhar was selected for the

1851 Exhibition scholarship and left for Cambridge in 1954. Later, Bhat left for the USA under a Fulbright grant and took his Ph.D. in physics at Ohio State University. In 1956, Ramdas left to take up a post-doctoral position at Purdue University in the USA. Soon after Ramdas left, Krishnamurti, Viswanathan, Pancharatnam and myself were all appointed as Assistant Professors at the Raman Research Institute, on a pay scale of 600-50-1000. With free housing, it was not a bad situation. We all continued with our work, which involved helping Raman whenever he wanted us to and, during the rest of the time, pursuing those of our studies approved as worthwhile by Raman.

Some time in the early part of 1960, the Vice-Chancellor of Mysore University requested Raman to recommend a few physicists for the physics faculty in the newly created postgraduate centre at Mysore. Raman felt that he should only recommend the very best men, especially those in whom he had the highest confidence. Accordingly, he considered recommending Krishnamurti, Viswanathan and Chandrasekhar who was by then getting ready to return from England. He mentioned all this to me and said: "I could also recommend you, but I want to have you as well as Pancharatnam with me. This is a good opportunity for the rest of them."

I left the Raman Research Institute in October 1960 for the University of California, Los Angeles, USA, to work at the Institute of Geophysics there with Prof. George C. Kennedy in the field of High Pressure research. Raman was very unhappy over my decision to leave his Institute and was very upset that I wrote to Kennedy without his knowledge. Unfortunately, I had to do this in a sneaky fashion because I knew how Raman would have reacted if I had told him about it beforehand.

For many years he had been telling me that he was sick of people taking a Ph.D. and using it as a passport to go abroad. I had approached him many times for his permission to submit some of my studies towards a Ph.D. degree. He would always remark: "Look here, I don't attach any importance to degrees and you see I never took a Ph.D. in my life. Why do you want a Ph.D.? Whether you

have a Ph.D. or not, it does not make any difference to my estimation of you." Usually, after this argument from him, I would not press my point. On one occasion, he further elaborated what was in his mind. He said, "You see you will get a Ph.D. and then leave me, to go to some laboratory abroad". I perfectly understood his viewpoint; he did not want this scenario to happen in my case. Both of us got on extremely well and, in some sense, I had become somewhat indispensable to him in his mind. My affection, loyalty and respect for him were something extraordinary and I don't remember doing anything that displeased him in any way.

At some point early in 1960 Raman finally agreed that I could submit a Ph.D. thesis if I was so keen about it. I was by then getting a little bit restless at the Institute and, having spent more than a decade there, I wanted a change. It was marvellous to be associated with a great scientist and be under his protection. However, I began to feel that I should go out and make it on my own. Hence I wrote to a friend, Dr Sourirajan, who was at that time working in Kennedy's laboratory at UCLA. I had read some of Bridgman's papers and had developed some interest in the field of High Pressure research. Sourirajan encouraged me to write to George Kennedy and I acted on his suggestion. Within a fortnight I had an offer of a post-doctoral research fellowship, with the title Assistant Research Geophysicist, to work in Kennedy's laboratory, even though I had not yet obtained my Ph.D.

Kennedy had suggested in his letter that I could get a Ph.D. at UCLA while working on my research assignment. This was the letter I showed to Raman. He got very upset and angry with me. I explained to him that I would like to have a different experience and see a little bit of the world, that this desire prompted me to write to Kennedy. I told him that after spending two years in California, I would return to the Institute. He said: "No such thing. If you leave, you don't come back to my Institute." I told him, "Sir, if that is your decision I feel myself very unfortunate, but I have decided to go." Then he read and reread Kennedy's letter and said: "All right, you

submit your Ph.D. thesis and then go. But you see, you can't come back here and I don't know what you will do when you return." I really felt miserable that I would be leaving the Institute forever and that too after having earned the displeasure of my mentor and revered guru.

In the next few months I wrote my Ph.D. dissertation and submitted it to the University of Madras. I left Bangalore on October 12, 1960, for California. The fact that I might be becoming one of those stereotypes he had talked about bothered me very much. But the time had come for us to part company and, with a heavy heart and tears in my eyes, I took leave of my beloved Professor. For eleven years I had been a close companion and confidant to him and he had, in turn, treated me with utmost kindness and consideration. He made me a research scientist and a physicist. I learned from him how to appreciate nature, see loveliness and beauty in things, and the methodology of research. Many times he had told me: "If you are interested in a subject, start your own study on it. You will definitely find something new that others have missed. It is the application of a keen and observant mind that is important. You can do the literature survey later." This has proved to be so true for me in many of my studies.

After I left in October 1960 he was very upset and recommended all his research team, including Pancharatnam, to the Mysore faculty. Apparently he offered Pancharatnam a Professorship at the Raman Institute which, I was told later, Pancharatnam declined to accept. They were all appointed by the Mysore University, but later there was a court case connected with the appointments when some aggrieved party alleged favouritism. I believe Raman had to appear in court and give evidence. Finally, everything turned out all right, but this turn of events was very unfortunate because Raman wanted to do the best for the University and got hurt in the process. All the persons involved represented the best men with him at the time and there was no question of any favouritism.

After all this, Raman became very cynical in his attitude and refused to take anyone into the Institute. With the assistance of

Padmanabhan and Balakrishnan he continued to pursue his scientific interests until his death in 1970.

I visited India in 1964 and called on Raman. I could feel that he was still upset with me for having left him, but I walked with him in the garden for some time and told him about my work in High Pressure research. He had grown weaker, but his health was still good for his age.

Raman maintained his health remarkably well until a few months before his death. His walks, dietary habits and means of relaxation helped him to keep good health. When I joined him in 1949 he was 61 years old and was in very good shape. He had evidently developed hernia some years before and used to wear a belt for this, but around 1952 the condition bothered him so much he had to undergo surgery for it. Lady Raman took him to Vellore American Mission Hospital and had the surgery performed by the well-known American surgeon Dr Sommervel, who was at that time serving at the Mission Hospital. Raman was a difficult patient. Lady Raman told us that she had a tough time keeping him in bed while recuperating and had to report the matter to Sommervel. The doctor apparently had to admonish Raman, telling him that if he did not follow his instructions, he (Raman) would croak and he (Sommervel) wouldn't be able to do anything. Raman seems to have followed instructions after that and, after a ten-day stay in the hospital, returned to Bangalore. The hernia problem disappeared after the surgery and Raman kept good health thereafter, except for minor illnesses.

Lady Raman used to bring a Dr Subba Rao, the resident doctor at the Indian Institute of Science, to treat Raman for any minor illness. Raman liked Subba Rao very much, for the latter would go along with his wishes.

The founder's wish

Raman had bequeathed all his personal wealth to his Research Institute and desired a bright future for it. He was very much against accepting grants from the Government, for he feared that would destroy the freedom necessary for carrying out fundamental research.

When the Education Minister, M. C. Chagla, once offered the Government of India's support, Raman said: "Sir, I want this Institute to be an oasis in the desert, free from government interference and the application of its rules and regulations. That would destroy my Institute. Thank you for your offer."

Raman had very definite ideas about how a research institute should come into existence, how it should be managed and what kind of persons should work therein. During his lifetime, he expressed his views about such matters on several occasions, but what he stated only a few days before his death is worth reproducing here. This, almost in his own words, was recorded by one of his associates:

> "The Raman Research Institute was created by me in 1948 to provide a place in which I could continue my studies in an atmosphere more conducive to pure research than that found in most scientific institutions. To me the pursuit of science has been an aesthetic and joyous experience. The Institute has been to me a haven where I could carry on my highly personal research work. This personal character of the Raman Research Institute should obviously change after me. It must blossom into a great centre of learning, embracing many branches of science. Scientists from different parts of India and from all over the world must be attracted to it. The foundations of such a centre have already been laid. With its beautiful gardens, large libraries and extensive museums, I feel that the Institute offers a perfect nucleus for the growth of a centre of higher learning.
>
> I have always felt that science can only flower when there is an internal urge. It cannot thrive under external pressures. I strongly believe that fundamental science cannot be driven by instructional, industrial, Governmental or military pressures. This was the reason why I decided, as far as possible, not to accept money from Government. I am a very practical man and I am practical enough to see that it would not be possible for others to run or grow a good institution without funds. I have bequeathed all my property to the Institute. Unfortunately, this may not be sufficient for the growth of this centre of learning. I, therefore, will not put it as a condition that no Governmental funds should be accepted by the Institute; I would, however, strongly urge taking only funds that have no strings attached.

> The full potential of this centre of learning can only be achieved by exceptional leadership. Among the many qualities called for in a person who assumes this responsibility are scientific integrity, vision, receptiveness to new ideas and an enlightened outlook, to let younger people grow unhindered to their full height. If these qualities can also be combined with the scientific reputation acquired by significant personal contributions in a chosen field of endeavour, one has a leader who is likely to succeed in developing the Institute and incidentally rendering the nation a service. Any person who assumes the responsibility of running the Institute must have full control of the laboratories, libraries, workshops and other facilities. He must be empowered to acquire and dispense money in the name of the Institute. He must have powers to appoint or terminate the services of personnel required for the running of the Institute. Nothing is so detrimental to the growth of Science in an institution than the existence of deadwood floating aimlessly, unable to participate in the scientific growth of an Institute."

It is quite apparent that, in his own mind, Raman regarded the Institute as a place for his work during his lifetime and, after that, as a legacy to the succeeding generations of scientists in India. On one occasion, when he was provoked by a news reporter, he said, pointing towards his laboratory: "This Institute is a monument to my egotism. I am an egotist, and just as the Egyptian Kings used to build pyramids before their death, so is this Institute my pyramid." Although this statement, taken out of context, appears to give prominence to the ego in Raman, it is no more than an expression of the uncommon degree of self-confidence which Raman always displayed in his own methods of work. On the same occasion, he went on to say: "You know I was in the Indian Institute of Science and was due to retire at 60. So, two years before my retirement, I started building this Institute so that on the day I retired I took my bag and walked into this Institute. I cannot remain idle for a single day." That was the main purpose for which the Raman Research Institute was built by Raman and, indeed, it served the purpose so fully and so admirably

that it enabled Raman to work there almost every day of the twenty-and-odd years that he lived after retirement from his formal position at the Indian Institute of Science.

Raman was appointed as National Professor for life (the first such appointment) by the Government of India, after his retirement from the Indian Institute of Science, to enable him to pursue his interests at his new Institute. There is a story that a feeler was sent to him to find out if he would accept the Vice-Presidency of India. He is reported to have had a hearty laugh and said, "What would I do with it?". Raman was never a member of many committees and he resigned in later years from even the few he was connected with. He even resigned his Fellowship of the Royal Society. All that mattered to him in the last two years was the pursuit of his scientific interest and the future of the Raman Research Institute.

The last years

Isolation from other scientists in India, arising partly from his disappointment with the trends that the growth of Science in India was showing, and partly from his desire to devote himself wholly to his chosen lines of work, was a noticeable feature of the last few years of Raman's life. He was generally critical of post-Independence scientific developments in India and became more strongly so as time went on. He bitterly complained against the growing dependence of Indian scientists on foreign institutions for their equipment and support and even for their ideas. He disapproved of young men going out of India to build scientific careers. However, during the last two decades of his life, the times were such that the so-called 'brain drain' was gaining momentum in India as in other developing countries.

He disapproved of organisations spending large sums of money on equipment and often said that where there is creativity of mind, the magnitude of external tools does not matter. But the expansion in independent India was such that large sums of money came to be invested on National Laboratories and other Government-controlled scientific institutions. Thus, the widening gap between his

approach to Science and the way India's scientific development was going alienated him from the mainstream and he became somewhat cynical in his attitude. When the late Jawaharlal Nehru, then Prime Minister of India, admonished India's scientists and asked them to come out of the ivory towers in which they had confined themselves, Raman reacted in typically sharp manner and said: "The men who matter are those who sit in ivory towers. They are the salt of the earth and it is to them that humanity owes its existence and progress."

Many persons used to write to him and ask him for his views on matters of general interest. During the last years of his life, only rarely could a comment be elicited from him on a topic which was not related in some way or the other to Science, at least in its wider perspective. To one such query from an Indian scientist working in the United States, Raman gave a reply in a letter dated June 16, 1964, in the following words: "My personal philosophy of life about which you wish me to write is sufficiently indicated by the facts of my career. My first scientific paper was published in the *Philosophical Magazine* of London in November 1906 when I was just 18 years of age. I am now over 75 years and do not recollect any time during this long period when I took my mind off from my scientific interests. Today I am as active as ever." This reply contains statements which are typical of Raman's attitude to life.

To celebrate Raman's 80th birthday, the late Vikram Sarabhai organised the annual meeting of the Indian Academy of Sciences in 1968 at the Physical Research Laboratory in Ahmedabad. The meeting was held early in December. I specially came to India from the USA on this occasion, to see Raman and to felicitate him. Raman was in excellent spirits and moved freely with the scientists gathered there, joking and laughing with them. I presented Raman with a collection of synthetically grown crystals from Bell Labs and synthetic diamonds grown at General Electric Research Laboratories, Schenectady. F. P. Bundy and W. H. Wentorf, who had kindly given the diamonds to me, had arranged them on a base to look like the letter R and had set a plastic lens over them, so that the letter could be seen with the naked eye. When I presented the collection to him,

with some appropriate remarks, Raman was visibly moved. Later, during the conference, he seems to have remarked to someone: "Jayaraman knows how to touch my heart. Unfortunately I am unable to do anything for him in return that is good enough to attract him back to the country".

There was an evening dinner on the lawns of the Physical Research Laboratory to felicitate Raman. Seated with him at the centre table were a galaxy of Indian scientists, both Raman's old students as well as other distinguished scientists. At the end of the dinner, there were speeches in which a number of scientists paid tributes to Raman, highlighting his achievements and the important role he had played, directly or indirectly, in moulding their scientific careers. I remember distinctly that when G.N. Ramachandran tried to speak, he was so overcome by emotion he broke down and could not proceed beyond one or two opening sentences, before sitting down. Finally, it was Raman's turn to reply.

C.V. Raman and Vikram Sarabhai during the Indian Academy of Sciences annual meeting held in Ahmedabad in December 1968. The Academy honoured Raman on his 80th birthday at this meeting.

Group photo taken at the 1968 Annual Meeting of IASc in Ahmedabad. Celebrating Raman's 80th birthday.

He started by saying: "You know, people may be wondering why I wear a turban in this day and age. I will tell you why. The turban is a bandage to prevent my getting a swollen head after hearing such speeches...." He looked at the sky, the stars and the lovely trees around. He started talking about the wonder of Nature, the excitement which comes from a search for truth and the humility that a true scientific pursuit instils in one. He remarked that there was so much to be studied and understood that he felt that he had not accomplished anything worthwhile in his life. He referred to Pascal's saying, "Knowledge is like a sphere in space; the greater its volume, the greater is its contact with the unknown". He went on: "You have all spoken in praise of my work and achievements, but I am not satisfied with what I have done. What am I, compared to great scientists like Einstein!" Raman referred to the enormous opportunities which modern biological research had opened up for an understanding of the meaning and mechanism of life processes. The impromptu remarks he made after dinner on that occasion left an indelible impression on everyone present.

Towards the end, he became an institution in himself and, as loneliness surrounded him, work became all that mattered to him in life. When he fell ill, and was confined to bed, the end coming nearer and nearer, be told his doctors, "I do not want to survive my illness if it means anything less than a hundred per cent active and productive life". Less than a couple of months before his death, he went up to the first floor of the Raman Research Institute, seemingly as active as a young schoolboy, and delivered the Gandhi Memorial lecture on October 2, 1970. It was the last lecture he gave in his life and consisted of a masterly exposition of his ideas about the theory of hearing, once again illustrating his breadth of interests. This incident is more than proof that he not only believed in work, but also practised what he believed in, by keeping himself active till the very end.

In October 1970 I arrived in Bangalore to spend a sabbatical year and to set up facilities for High Pressure research in India. My first duty was to pay my respects to my *guru*. In December 1968, when I

saw him in Ahmedabad, he became tired very easily. In the intervening period, between January 1969 and October 1970, he had suffered setbacks in health and was not his old self. I saw him in his bungalow briefly and he got out of bed to talk to me, in spite of Lady Raman's protests that he should not do so. That was, unfortunately, to be my last conversation with him. In a few days he went into hospital after a heart attack. His condition appeared to improve at first, but within a few weeks he died. He passed away in the early hours of the morning of Saturday, November 21, 1970. By a special arrangement, his mortal remains were cremated in the grounds of the Raman Research Institute. Thousands of people, schoolchildren, students and others from all walks of life thronged the Institute precincts to pay homage to the memory of a great man.

Death is inevitable, but you don't want it to come to someone who changed your life and made it worthwhile. I was in silent tears that my revered *guru* had passed away, but it was some consolation that I could be present when his soul was consigned to eternal peace. I would have felt very badly had I missed paying my homage and last respects to Chandrasekhara Venkata Raman, that legendary figure of Science in modern India.

After Raman passed away, his younger son, V. Radhakrishnan, an eminent Radio Astronomer, took over as the Director of the Institute. In the last 16 years, the Institute has grown beyond recognition and is bustling with research activity in liquid crystals, astrophysics and radio astronomy. The budget has grown beyond anything Raman would have imagined and the Institute is now largely supported by grants from the Government of India.

Chapter III

Visitors, associates and others

Raman loved to talk about his Institute, his research and about himself. When he was in a good mood, you could not meet a person more inspiring and lovable than him. In the event he was in a bad mood, it was prudent to stay away from him. Princes and politicians, statesmen and scientists, students and teachers regularly visited the Institute to see Raman and talk to him. He gave them an enthusiastic welcome and took them round the museums, lecture theatres and on to the verandas or the portico for a view of the distant vista and the surrounding gardens. He talked to them about his current activities and sometimes took them into the laboratory for a first-hand experience of the phenomenon he was studying.

To some he showed his memorabilia, the medals, the honorary doctoral gowns and the precious gifts he had received. Among these the Nobel Diploma and the Nobel Medal figured prominently. The Diploma was of exquisite calligraphy in a tastefully decorated format. The heavy gold medal with Alfred Nobel in relief on it was something everyone wanted to touch and feel. The honorary doctoral gown of the University of Paris was a very impressive and colourful piece of dress with cap to match. Raman would have looked majestic when he walked down the aisle, along with the academics of the University of Paris, to receive the honorary doctorate conferred on him. He once told me that he had earned only a Master's degree in

physics; all the doctorates were *honoris causa*. Raman kept all his memorabilia locked in steel almirahs in his downstairs room and the keys to these secured in a steel safe.

He had an elaborate system of locks and keys to the laboratories and steel cabinets. In the beginning, only he would open the safe and give the keys to the museums, or to any other room to be opened. As time went on, he gained confidence in me and Padmanabhan and allowed us access to the heavy steel safe. Each bunch of keys to the rooms and cabinets had its allotted place in the safe and we were instructed to strictly adhere to the arrangement. It was a sight to see Raman walking with a bunch of keys and opening the rooms himself for visitors. We received a duplicate set of keys to our laboratory rooms. In respect of keys, he treated me with special consideration and trusted me with the master key to the safe, whenever he went out of town for any length of time. The reason for all the safety and precaution was understandable in view of the precious nature of things he kept.

In the early days of the Institute, Raman was quite generous in admitting visitors and taking them round himself. Sometimes he would ask me or Padmanabhan to show visitors around. Later, he found visitors a great impediment to his work and for the peace and quiet he needed. So he began to discourage visitors, except the very important ones. He even installed a notice board at the entrance to the Institute, "No Admission to Visitors".

Among the eminent scientists who visited Raman, the following come to mind: J. D. Bernal, H. J. Bhabha, E. C. Bullard, S. Chandrasekhar, C. G. Darwin, P. A. M. Dirac, J. B. S. Haldane, Linus Pauling, C. F. Powell, Norbert Wiener and G. Wentzel. The annual Indian Science Congress, usually held every January, used to sponsor the visits of foreign scientists for its meetings. Most of these scientists would come to Bangalore, for it was not only an important centre for science but India's most distinguished scientist also lived and worked there. In addition, Bangalore is a lovely city with many attractions for the visitors and is the gateway to Mysore — one of the most colourful cities in India, famed for its *Maharaja's* palace, the

Krishnaraja Sagar reservoir and for the nearby Bandipur game sanctuary. The Indian Institute of Science and Raman Research Institute would be on the itinerary of every visiting scientist.

The Russian scientific delegation used to be the largest of all the scientist groups in those days and was quite visible at every Science Congress. These delegations would have someone at the level of an Academician as the leader and a number of younger scientists accompanying him. The Russian scientists without exception came to visit Raman. At one time, Raman was out of town and we had to take care of one such Russian delegation. Academician N. V. Belov, a well-known Russian crystallographer, was the leader. There were also a number of young scientists with him. They were so disappointed with Raman's absence that they had their itinerary rearranged so that they could visit the Institute again, a week or so later, when Raman was back.

Apart from these invitees to the Science Congress, other eminent scientists from abroad came as special invitees of the Government of India and Bangalore was always on their itinerary. Therefore Raman had visitors the year round. He generally showed great enthusiasm in receiving them and taking them around. He lectured to them on his latest findings. At other times he tried to convince them of his views. One of his favourite topics was his lattice dynamical theory; he was severely critical of the viewpoint of Max Born on this subject. Although Raman had invited Max Born to Bangalore in the Thirties and had deep regard for Born as a physicist, he was totally opposed to Born on the theory of lattice dynamics. Some of the visits of prominent scientists to the Raman Institute during the period between 1950 and 1960 are described below and in the following pages.

J. D. Bernal

Bernal was one of the earliest distinguished visitors to the Raman Institute. I think it was the 1950 Science Congress for which he was invited and he came to Bangalore after participating in it. Raman took Bernal round the Institute with great enthusiasm and showed him some of the experiments that we were doing at the time using

sunlight. Bernal was a brilliant X-ray physicist, crystallographer, crystal physicist and crystal chemist, all rolled in one. He had a keen mind and a very scholarly look.

Bernal was, at the time, a Professor at Birkbeck College, London. He knew of Raman's work on lattice dynamics and the raging controversy between Raman and Max Born. He was even more conversant with the controversy over diamond in which Raman and Kathleen Lonsdale were involved. This related to the X-ray diffraction effects in diamond (the so-called extra reflections). Whenever Raman talked about these things, Bernal smiled enigmatically, but his remarks were measured and he did not endorse the explanations that Raman offered or his views.

One afternoon, Raman offered to take him round Bangalore in his Willys sedan. Raman's younger son, Radhakrishnan, and I also went with them. After visiting Cubbon Park and Lalbagh, we ended up at the Bull Temple in Basavanagudi. One of the most impressive sights in this temple is the gigantic stone bull at the entrance. Raman explained to Bernal the role of the bull in a Siva temple. Then we went near the *sanctum sanctorum* and there was this Trident — the famous weapon of Siva — just outside the inner chamber. Bernal asked about the significance of the Trident and its purpose and Raman explained it to him. It was a very pleasant outing, which we all enjoyed very much.

H. J. Bhabha

Bhabha was one of the most eminent physicists of India. He was mainly responsible for founding India's Nuclear Energy programme. He was born in 1909 in Bombay and was connected to that well-known industrial family, the Tatas. He initially enrolled in Gonville and Caius College in Cambridge in 1927 to study mechanical engineering, but switched to theoretical physics and took a B.A. degree in 1930. Paul Dirac was, apparently, one of his tutors. Bhabha received his Ph.D. in 1935 for his research on cosmic-ray-produced electron showers at the Cavendish Laboratory in Cambridge. He stayed on in Cambridge until 1939.

During this period he spent time with Fermi's group in Rome, Pauli's group in Zurich and Niels Bohr's Institute in Copenhagen. Bhabha's work with Heitler in 1937, on cosmic ray showers produced by muons, and other work in the field earned him a lasting reputation in theoretical physics. He returned to India in 1939 at the outbreak of World War II for a vacation and, fortunately for India, could not return to Cambridge.

He joined the Indian Institute of Science as Professor of cosmic ray physics. Raman was at the time heading the Physics Department and encouraged Bhabha. With Raman's support, and through his own Tata connections, Bhabha was able to create a new Institute particularly devoted to research on cosmic rays and nuclear physics. The Tata Institute of Fundamental Research was founded in Bangalore in June 1945 with Bhabha as its Director. It later moved to Bombay. When the Indian Atomic Energy Commission was established in 1948, Bhabha was made its Chairman. The Commission conducted most of its early research and development work at the Tata Institute of Fundamental Research.

Bhabha was a frequent visitor to Bangalore in the early Fifties, coming there to supervise the balloon flight experiments carried out by the cosmic ray research unit of the Tata Institute of Fundamental Research. Bhabha was actively involved in cosmic ray studies in those days and was regarded as a front-ranking scientist in the field. Raman and Bhabha were on very friendly terms and, during his Bangalore trips, Bhabha used to come to the Raman Research Institute to see Raman. On one occasion, he even brought his mother to the Institute.

Bhabha was very interested in art and himself painted. He drew a line sketch of Raman in 1949, a reasonably successful portrayal.

In the mid-Fifties Bhabha got deeply involved in India's atomic energy development project. He did an excellent job organising the Agency, the laboratories and the atomic energy programmes. He received considerable encouragement from Government and had direct access to Prime Minister Nehru. Consequently, his power and prestige increased enormously and he became the most influential

scientific administrator in India. He became the first Chairman of India's Atomic Energy Commission and held the post until his premature death in an airplane crash in the Swiss Alps on January 24, 1966.

Bhabha simultaneously held three important positions in India, namely, the chairmanship of the AEC, Secretary to the Government in the Department of Atomic Energy, and Director of the Tata Institute of Fundamental Research. Bhabha was a superb organiser and was able to function efficiently in all three capacities. However, he gave up active science himself to emerge as the most powerful scientific administrator in the country.

Raman hated big organisations and felt a big bureaucracy only wasted money. He began to feel uncomfortable with Bhabha and gradually the two drifted apart. Bhabha never visited Raman after 1954 and I think this upset Raman very much. He used to open up the latest research volumes and ask visitors: "Do you find the name of Bhabha anywhere in the scientific literature nowadays? He has quit Science."

E. C. Bullard

Bullard was Director of the National Physical Laboratory in England at the time he visited India and called on Raman in Bangalore. Bullard immensely enjoyed Raman's conducted tour of the Institute. On this occasion, Raman showed him all his personal memorabilia, including the Nobel Medal, the Nobel Diploma, the Hughes Medal of the Royal Society, the Franklin Medal and the Matteucci Medal. Several colourful doctoral gowns worn by Raman during the award of Honorary Doctorates were also shown to Bullard. Bullard was particularly interested in Raman's relationship with Rutherford. Raman had a great regard for Rutherford and spoke highly of him and his majestic personality. Rutherford strongly endorsed Raman's candidacy for the Nobel Prize and supported him on several occasions. Raman and Rutherford had many similarities. Both were very powerful, domineering personalities, and led very active schools of physics in their respective countries.

S. Chandrasekhar

Subrahmanyan Chandrasekhar, the distinguished Professor of the University of Chicago, was Raman's nephew. He won the Nobel Prize for Physics in 1982 for contributions he had made to astrophysics almost fifty years earlier.

Chandrasekhar was born in 1910 in Lahore and took his B.Sc. Hons. degree in physics in 1930 from Presidency College, Madras, the same college that Raman had gone to some 25 years earlier. When Chandrasekhar was finishing his B.Sc. Hons. degree, Raman had just then won the Nobel Prize for Physics. Therefore the influence of Raman's life on young Chandrasekhar must have been strong. The bright young physicist set the highest goals for himself and left for Cambridge to pursue higher studies in physics.

He turned to theoretical astrophysics, inspired by a book by Eddington that he had received as a prize. Even as a student at Presidency College, Madras, he had given thought to fundamental astrophysical problems and some of the important ideas concerning the fate of a dying star crystallised in his mind on the voyage to England. While in Cambridge, he came into contact with the celebrated astrophysicist Eddington himself and discussed astrophysics on a day-to-day basis with him. Chandrasekhar's work in Cambridge led to a rigorous solution to the puzzle concerning the fate of a star which had gone through its nuclear burning cycles and begun cooling. On January 11, 1935, at a meeting of the Royal Astronomical Society in London he presented a paper on the subject, in the presence of Eddington. Immediately after Chandrasekhar's presentation, Eddington got up and vehemently criticised Chandrasekhar's theory.

According to the ideas prevailing then, a cooling star would undergo gravitational collapse, and become a dense ball called a white dwarf. Chandrasekhar studied this collapse when the gravitational force was sufficient to overcome the counteracting electronic pressure of the compressed dense gas arising from the operation of the Pauli exclusion principle. Chandrasekhar proved conclusively that a star with a mass greater than 1.4 solar mass would collapse into

dense matter in which the electrons have velocities close to that of light — a state called relativistic degeneracy. This would cause the star to go on collapsing beyond the white dwarf stage, losing energy through radiation until it becomes so dense that light is trapped and the star vanishes. Such a situation is now known as a black hole, but at that time examples of white dwarfs, neutron stars — a dense star consisting of only neutrons — or black holes were unknown to observational astronomy.

Chandrasekhar's theory had far-reaching consequences, and modern astronomy and astrophysics have vindicated his conclusions. Eddington, however, did not like to believe in such an ignominious fate for a stellar object and, hence, opposed Chandrasekhar's brilliant and fundamental contribution. The latter felt undermined by this and was deeply disappointed with Eddington's attitude.

In 1936, Chandrasekhar migrated to Chicago to accept a professorship at the University of Chicago and remained there since. He changed his subject to radiative transfer, stellar structure and magnetohydrodynamics, but in later years worked on black holes again. He then got interested in general relativity. In each of these areas he made monumental contributions. Finally, due recognition for his original contribution came in 1982 when he was awarded the Nobel Prize for physics, which he shared with William A. Fowler of the California Institute of Technology. Chandrasekhar's books on magnetohydrodynamics and black holes are classics.

Chandrasekhar visited Bangalore in 1951. This, I believe, was his first visit to India after he moved to Chicago in 1937. He was then near 40. The Chandrasekhars stayed with Raman. Raman's remark on meeting Chandrasekhar is noteworthy. Commenting on the fact that Chandrasekhar had not been back in a long time, he said, "You are visiting India like Halley's comet". Raman was quick-witted and would say the most unexpected things.

When Chandrasekhar visited the Raman Institute, we had no electricity, but a lot of light-scattering experiments were going on with sunlight. We were studying the diffusion of light in moonstone at the time. Raman had shown that the geometry of the observed

halo and its dimensions contained information about the size and shape of the particles responsible for the optical heterogenety and we had worked out that these could be estimated using a simple optical diffraction theory. Raman demonstrated the effect to Chandrasekhar and the latter was quite impressed by the optical phenomena and the explanation offered by Raman. He suggested that Mie's theory of scattering could be applied to the situation. However, Raman's simple approach and the explanation he advanced was an intuitive jump over any mathematical theory. Chandrasekhar was shown some of the other experiments that were going on at the time, using sunlight. One of them was the luminescence of diamond, which always impressed visitors.

Raman was very proud of Chandrasekhar's achievements and proposed him for the Nobel Prize as early as the Fifties. During that visit to Bangalore, Chandrasekhar gave a lecture on 'The Polarisation of the Sunlit Sky' at the Indian Institute of Science before a huge audience. Raman, who sat in the front row, appreciated the masterly presentation very much.

C. G. Darwin

Darwin, a famous X-ray physicist from England, came to Bangalore to meet Raman. A visit to the Raman Institute and a dinner at Raman's home later in the evening had been planned. Darwin came to the Institute in the morning and Raman, as was customary, took him round the laboratories and the museums. Then he talked about his lattice dynamical theory with a view to gaining approval of his ideas. He gave a well-prepared lecture for 45 minutes. Darwin listened to it and then responded, "I don't agree with your ideas".

Raman was infuriated. Very upset, he said: "I wasted my time. You are all prejudiced. I should have known that this business of trying to convince a British physicist is as bad as trying to unbend a dog's tail". Darwin was no younger than Raman and he was taken aback by these remarks. Suddenly the warmth and enthusiasm that Raman had shown Darwin evaporated. When taking leave of Raman later that morning, Darwin actually doubted whether the dinner

engagement was still on. He asked Raman, "Are we meeting for dinner?". Raman replied, "Yes, yes — we are having dinner at my house in the evening". But Raman continued to feel that the whole British School of Physicists was influenced strongly by Max Born and, hence, opposed to his views.

P. A. M. Dirac

Dirac's visit to the Raman Research Institute in 1954 was a very pleasant affair, with Raman very happy throughout. In fact, Raman had planned a three-day visit to Bangalore for Dirac and had filled it with so many engagements that he left very little time for Dirac even to visit the Indian Institute of Science. However, these plans got altered when Dirac arrived as the guest of the IISc. Nevertheless, he came to the Raman Institute and spent quite some time with Raman. The next day, Raman took him in his car to visit his country home and a nearby water reservoir called Thippagondanahalli.

When Dirac came to the Institute, Raman took him round enthusiastically and showed him everything that was to be seen there. He gave a talk on his lattice dynamics at the lecture theatre; this was attended by a few others as well. After the 45-minute presentation, Raman wanted to know Dirac's opinion about his theory. Dirac began to respond rather slowly. He started saying "What you presented appears reasonable", but before anything further was said Raman took Dirac's hand and warmly shook it, saying: "I know you will see my point of view. You are one of the greatest physicists for whom I have a great regard." Dirac could not, and did not, make any further comments. Raman was certainly under the delusion that Dirac agreed with him.

J. B. S. Haldane

Haldane was an eminent British biologist who fell in love with India and settled there in his later years. After he settled in India, he even wore *dhoti*s in the Bengali fashion and thus identified himself with the country totally. He made Bhubaneswar in Orissa state his home and carried on research in biology, agriculture and statistics applied to biology.

Haldane was one of those rare individuals who had a broad interest in Science. He knew mathematics, physics, chemistry and biology. He was a tall, hefty figure and had a commanding personality.

His trip to the Raman Institute was memorable. He gave a talk at the Indian Institute of Science in the morning and was to visit the Raman Institute after the talk. He refused the car that was arranged to take him to the Raman Institute and walked the one mile at a brisk pace. A lot of admirers walked with him; it was like a *Padayatra* (pilgrimage on foot) to the Raman Institute.

Raman received him at the portico and conducted him through the Institute. His first remark was: "Prof. Haldane, why did they make you walk? I would have sent my car." To this Haldane replied that he preferred to walk and enjoyed the exercise very much. Raman took Haldane round his museum and proudly showed him his bird and mollusc collection to impress him that his interest in biology was a match for Haldane's.

Mark Oliphant

Sir Mark Oliphant, a distinguished Australian nuclear physicist who had worked under Rutherford, came to India in 1956 to deliver the Rutherford Memorial lecture. Alladi Ramakrishnan, the Director of the Mathematical Sciences Institute, Madras, had invited Oliphant to deliver the lecture in Madras. Oliphant had a written lecture and was planning to deliver the same lecture in both Madras and Bangalore. It was arranged that the lecture in Bangalore would be chaired by Raman.

Ramakrishnan narrates how a reporter from the Madras daily, *The Hindu*, interviewed Oliphant and planned to publish the gist of the lecture. But as the reporter left, Oliphant inadvertently handed him the entire transcript of the lecture. The next morning, *The Hindu* carried the lecture verbatim over four columns, as a tribute to the great scientist Ernest Rutherford. Raman read the speech in *The Hindu* and promptly called Oliphant, who had just arrived in Bangalore and was staying at the West End Hotel, to say that he had read the lecture given in Madras and that he had enjoyed it very much.

Oliphant, it seems, was quite embarrassed about it, since he could not give the same speech again, especially with Raman in the chair. Fortunately he had another version, which he delivered and thereby avoided any amusing comments from Raman.

The lecture by Oliphant was given at the Sir Puttannachetty Hall in Bangalore before a distinguished audience of scientists, students and general public. I was in the audience and heard Raman speak in glorious terms about the lecture and about Rutherford.

Linus Pauling

Pauling visited Bangalore in 1954 and came to see Raman. Raman took him round with great enthusiasm and showed him his exquisite collection of gems, minerals and crystals. He also gave a short talk on his lattice dynamics and waited for Pauling's comments. Pauling, however, did not commit himself and merely said, "I will have to think about it more deeply".

Pauling had been awarded the Nobel Prize for chemistry shortly before he visited India. In the upper portico of the Raman Institute quite a few scientists had assembled on the day of Pauling's visit and someone remarked that Pauling had been awarded the Nobel Prize for chemistry. Raman promptly said: "I elected him to the honorary fellowship of the Indian Academy of Sciences years ago, knowing his worth. The Nobel Committee has recognised his greatness only now." Raman was evidently quite happy with himself for the remark and Pauling responded with a smile.

Raman had taken a little more time than was allotted for the visit. Pai, who was the Registrar of the Indian Institute of Science and who had been accompanying Pauling, made some rude remarks to Raman about his delaying his visitor. Pauling had to rush to the Indian Institute of Science to deliver a lecture on 'Sickle Cell Anemia and its Molecular Biological Basis'. It was strange that Raman let the remarks pass. We all felt that a nonscientist like the Registrar had no business to talk to Raman in that fashion.

C. F. Powell

Powell was a distinguished cosmic ray physicist from Bristol who came to India in 1956 at the invitation of H. J. Bhabha. Powell pioneered the use of the photographic emulsion technique for recording cosmic ray encounters as tracks in the plate, and discovered several new particles from the cosmic-ray-produced tracks on photographic plates. He won the Nobel Prize for Physics in 1950. M. G. K. Menon, a well-known Indian scientist turned scientific administrator, worked under Powell and participated in some of the experiments conducted in the early Fifties.

Powell visited Bangalore during his trip and called on Raman. The latter wanted to trace the origin of the use of the photographic emulsion technique in recording cosmic ray encounters and I remember him going to the Indian Institute of Science Library to investigate. After much searching Raman found that Blau and Wambacher had in 1907 discovered the photographic emulsion technique whose use Powell had pioneered. Raman triumphantly talked about his findings to Powell and the latter was amazed by Raman's curiosity and thoroughness.

Those were great days for cosmic ray physics and cosmic ray physicists. Powell gave a scintillating talk and Raman enjoyed the lecture very much.

S. Bhagavantam

Bhagavantam joined Raman as a research scholar in Calcutta at the comparatively young age of 18 and Raman intuitively recognised the great potential and precocity of the young scientist. Bhagavantam commenced his research career with investigations on the optical and magnetic anisotropy in aromatic and aliphatic series of compounds and established the relationship between the magnetic behaviour of organic crystals and their molecular form and crystal structure. Soon after the discovery of the Raman Effect in 1928, Bhagavantam took up the study of the Raman spectra of gases. His pioneering work on the effect of pressure on the Raman spectra of gases helped in

elucidating the influence of intermolecular collisions and viscosity on the rotational structure of the Raman bands in gases.

In 1932, Bhagavantam joined the Andhra University, Waltair, where he remained for sixteen years, becoming successively Professor, Head of the Department of Physics, and then Principal of the University Colleges. During this period, besides continuing his investigations on the Raman Effect, he established an active school of experimental research in ultrasonics and developed new techniques for the measurement of the elastic constants of crystals. His two books published during this period, namely *Scattering of Light and Raman Effect* and *Theory of Groups and its Applications to Physical Problems*, are still among the best books that any research worker can find on the respective topics. The second book, with Venkatarayudu as co-author, is perhaps one of the most important contributions to the understanding of the Raman spectra of crystals. Through the use of group theory, Bhagavantam and Venkatarayudu established the role of crystal symmetry in splitting the degenerate vibrational levels of molecules and molecular groups when they go into crystals to occupy positions of symmetry.

Bhagavantam possessed the rare combination of scientific eminence and administrative ability and consequently held a variety of important positions during his career. He was chosen as the first scientific liaison officer of independent India in the UK. On his return, he went to Hyderabad as Professor of Physics and started an active research school at the Osmania University. Later, he became the Vice-Chancellor of Osmania University. During this period, he initiated work in cosmic ray research, studies on high polymers and solid state physics, and published his third valuable book, *Crystal Symmetry and Physical Properties*. He also took steps to rejuvenate astronomical studies and research in Hyderabad.

From 1957 to 1962, he served as Director of the Indian Institute of Science, Bangalore. Later at the invitation of the then Defence Minister, V. K. Krishna Menon, with whom he had become friends during his London days, Bhagavantam became scientific adviser to the Ministry of Defence, Government of India. He also held many

other important professional positions and his career was one of laudable achievements.

Bhagavantam remained a loyal friend of Raman throughout and the latter had a special affection for Bhagavantam. He used to treat Bhagavantam very warmly and the latter, in turn, had a deep regard for Raman. I have seen them together on innumerable occasions, engrossed in discussion. Bhagavantam never failed to attend the Executive Council meetings of the Indian Academy of Sciences, of which I was a member, by virtue of my position as the Treasurer of the Academy, from 1956 to 1961. Bhagavantam hosted several annual meetings of the Academy while he was in Hyderabad and at Andhra University. In fact, the first Academy meeting I went to was in December 1950; it was hosted by Osmania University where Bhagavantam was the Director and Professor at the Physical Research Laboratory.

Raman used to enjoy Bhagavantam's lectures, which were notable for their precision, clarity and thoroughness. Bhagavantam died in February 1989 at the age of 80. When I visited him in the first week of December 1988, he recalled his Calcutta days and talked about Raman.

K. S. Krishnan

K.S. Krishnan joined Raman in Calcutta as a research scholar in 1923. Krishnan was a very capable experimenter and worked on several problems in optics and magnetic and electric double refraction in anisotropic molecules. Raman and Krishnan discussed, in a series of papers, the magnetic double refraction in liquids and the electric double refraction in relation to the polarity and optical anisotropy of molecules.

Krishnan's outstanding record of research won for him first the M.Sc. and, later, the D.Sc. degree of the Madras University. He assisted Raman in the light-scattering experiments at those very crucial stages which led to the discovery of the Raman Effect. The first few publications relating to the discovery, and the subsequent detailed papers, were published jointly by Raman and Krishnan. His col-

laboration with Raman continued up to 1930 when he accepted the Readership in Physics at Dacca University.

Krishnan continued in Dacca, with a band of dedicated scholars and post-graduate workers, his remarkable series of studies on the magnetic susceptibility of many organic and inorganic compounds. He returned to the Indian Association for the Cultivation of Science, as the first Mahendralal Sircar Professor in 1933, when Raman left Calcutta to take up the Directorship of the Indian Institute of Science in Bangalore. A few years later, Krishnan was elected as a Fellow of the Royal Society, London. He moved to Allahabad University as Professor of Physics in 1942. There, he became attracted to theoretical physics, influenced by A. B. Bhatia, a brilliant mathematician, who had joined him as a research student. Krishnan continued in Allahabad until 1947, carrying on an excellent research tradition.

The British Government conferred upon him the knighthood in recognition of his outstanding scientific work in Allahabad. Soon after, he accepted the invitation to become the first Director of the National Physical Laboratory in New Delhi, a position he held until his death in 1961. Krishnan received many honours and distinctions during his lifetime.

Krishnan had wide interests and was a noted scholar in Tamil. He was a very good speaker with a subtle sense of humour and was an excellent conversationalist. It appears that Prime Minister Nehru liked Krishnan very much and enjoyed a chat with him whenever he had some free time.

I first saw Raman and Krishnan together in Delhi in 1951, at the time the Indian Academy of Sciences' annual session was held there. Raman used to be the chairman of a committee called the Physical Research Committee instituted by the Council of Scientific and Industrial Research and Krishnan was a member of this committee. Consequently, Krishnan used to come to Bangalore periodically for these meetings and Raman and Krishnan were on very friendly terms. But after 1953, their relationship deteriorated and was completely destroyed.

It is difficult to fathom how this happened. Many versions were current at the time. In 1953, which was the Silver Jubilee year of the discovery of the Raman Effect, feeble voices were heard whispering that Krishnan had played a significant role in the discovery. These reached Raman's ears and, lacking the patience to verify the veracity of these stories and their source, he jumped to the conclusion that Krishnan entertained such ideas. He felt humiliated and let down, and began to regard Krishnan unfavourably. Friends and well-wishers of both were helpless in this drama. Raman's feelings were so strong, they caused much anxiety in the minds of many. This was a very unpleasant episode in the life of Raman and Krishnan.

Unfortunately such views still find expression. For instance, Sankar Chakraborty states in the *Calcutta Municipal Gazette* of November 2, 1988: "In the discovery of the Raman Effect, K. S. Krishnan played a very significant role. Many have felt that K. S. Krishnan should have been acknowledged as the co-discoverer of the effect now bearing Raman's name exclusively." You go into the history of the discovery of the Raman Effect, it is very clear that the light-scattering programme was initiated and led by Raman in Calcutta, soon after he returned from his first European trip in 1921. During the years 1921 to 1928, Raman had several collaborators working with him on the subject, and they included K. R. Ramanathan, K. Seshagiri Rao, S. Venkateswaran, K. S. Krishnan and a few others. Of this team, Krishnan undoubtedly was involved very much in the final phase of the discovery and there was therefore a very close and intense collaboration between Raman and Krishnan. In such a collaboration, only the two participants can speak about their roles and it would be impossible for outsiders to assign credit. Further, the Nobel Committee goes thoroughly into these matters and they seem to have had no difficulty in identifying Raman's leading role in the light-scattering programme in Calcutta, which culminated in the discovery of the Effect which his scientific peers in the field at that time named as the 'Raman Effect'. It is to be noted that the Nobel citation for Raman reads "for his investigations on the scattering of light and

the discovery of the effect known after him". It is not just for the final discovery alone.

Raman has generously acknowledged the assistance of Krishnan in the discovery, as well as the contributions of his other collaborators. Further, most of the papers relating to the new discovery bear the names of Raman and Krishnan. More importantly, Krishnan had never claimed in public that his contributions to the discovery were suppressed. An unbiased chronicler would have no difficulty in identifying the leading role played by Raman in the light-scattering work and would probably also conclude that Raman would have discovered the Effect without the assistance of anyone. However, it must be said that it was one of the most effective collaborations in the history of science; it certainly helped to bring the subject to a quick culmination at a time when the time element was very important. Otherwise, full credit for the discovery would probably have been lost, in light of the events that followed, namely the independent observation of the light-scattering effect by the Russian scientists Landsberg and Mandel'shtam, who were behind only by a few months.

To me it all sounds so sad and utterly futile to make an issue of this monumental contribution to Science by one of the most illustrious sons of India.

K. R. Ramanathan

Ramanathan was one of the earliest associates of Raman. He was born in Kalpathi, Palghat, in South India on February 28, 1893, about five years after Raman. He had his early education in Victoria College, Palghat, and took his Bachelor's degree in physics from the Presidency College, Madras. Then he joined *Maharaja*'s College in Trivandrum and served there as a lecturer for seven years. He joined Raman in Calcutta as a University of Madras research scholar towards the end of 1921 and collaborated with him in the studies of the molecular scattering of light and X-ray diffraction in liquids, gases and mixtures. Within a period of one year he had published ten papers and was awarded the D.Sc. degree of the University of Madras for his thesis based on this work. He then accepted a teach-

ing appointment in Rangoon in 1922, but continued to visit Raman's laboratory in Calcutta during the vacations.

During these periods, he conducted intensive examination of the molecular diffraction of light by water. Using sunlight and complementary filters, Ramanathan detected a weak residual light, which was dismissed as 'weak fluorescence' due to impurities. However, in later years, Raman pursued this very 'weak fluorescence' systematically and this pursuit led to the discovery of the Raman Effect in 1928.

In 1925 Ramanathan joined the India Meteorological Department and retired as its Deputy Director General in 1948. After his retirement he took up the Directorship of the Physical Research Laboratory at Ahmedabad and set up, for the first time in India, a group to investigate the physics of the upper atmosphere. He retired from the Directorship in 1966, but continued to work as Emeritus Professor.

He also helped Dr Vikram Sarabhai organise space physics research in its initial stages in India. Ramanathan was held in high regard by the Sarabhai family and was truly a friend, philosopher and guide to the young Sarabhai. He passed away in Ahmedabad on December 31, 1984, at the age of 91.

Raman had great affection and regard for Ramanathan. Since the latter was only five years younger, Raman treated him as a colleague. Ramanathan served the Meteorological Department with distinction for 23 years and there he established high scientific standards. He brought physics into meteorology and built up the department with outstanding physicists, who were mostly Raman's students. In those days, the only two avocations open to young physicists in India were teaching and as meteorologists in the Meteorological Department. Raman chose Ramanathan to high offices in the Indian Academy of Sciences. At the annual meetings of the Indian Academy of Sciences, Raman loved to hear Ramanathan expound on subjects connected with the upper atmosphere and atmospheric physics and enlisted him for public lectures at these meetings.

I have seen at close quarters the genuine mutual affection that existed between Raman and Ramanathan. To Ramanathan, Raman was a great hero and his beloved professor. To Raman, Ramanathan was a symbol of devotion and loyalty. Love and affection dominated their relationship. Only once was this relationship disturbed for a brief period. That was in 1953, when the Silver Jubilee of the discovery of the Raman Effect was being celebrated.

It was a minor incident in Bombay that strained this intimate relationship. Ramanathan inadvertently made a remark, during a public meeting connected with the celebration in Bombay, that Raman used the mercury arc by accident to discover the Raman Effect; that since it was a rainy day Raman had decided to use the mercury arc. Within a few days, a visitor from Bombay to the Raman Institute mentioned this to Raman, without realising the impact it would have on him. Raman was infuriated beyond control and totally lost his bearings. That was Raman's character when he was hurt. We did not understand at first why he was so upset, but the story soon unfolded.

Raman sent a telegram to Ramanathan asking him to come and explain to him why he had made such a statement. Ramanathan took the next plane and arrived in Bangalore to face Raman. Raman and Ramanathan were closeted in the former's office for a long time and then the two came out. Ramanathan issued a statement to the Press retracting what he had said and profusely apologised for the mistake he had made. After that, the relationship between Raman and Ramanathan returned to normalcy and the unpleasant episode was soon forgotten.

L. A. Ramdas

Ramdas joined Raman in Calcutta, in 1923, as a Palit Research Scholar and conducted experiments on the scattering of light by mercury and other pure liquid surfaces. Besides this, he investigated the optical properties of monomolecular films spread on water surfaces and the movement of surface-active substances like camphor on water. After obtaining his Ph.D. in Calcutta under Raman, he joined the India Meteorological Service in 1926, but continued to visit the

Indian Association for the Cultivation of Science in Calcutta during his vacations to actively work with Raman. It was Ramdas who named the light-scattering effect discovered by Raman as the 'Raman Effect'.

His work in the Meteorological Department was mainly involved with research problems connected with meteorology. He established and developed the new Division of Agricultural Meteorology in Pune, which specialised in the physics of the earth–atmosphere boundary layers. He pioneered research in this area. After retirement, Ramdas continued his researches in physics and atmospheric physics at the National Physical Laboratory in New Delhi.

Ramdas, who had a deep respect and admiration for Raman, was a frequent visitor to the Raman Research Institute in Bangalore. Another attraction for him in Bangalore was his son, A. K. Ramdas, who worked as a research scholar under Raman.

Ramdas had a fine sense of humour and it was a delight for us to listen to his stories about Raman's Calcutta days and about his own experiences with people. Ramdas wrote two very fine articles on Raman in the *Indian Journal of Physics Education* in 1971 and 1973. In these articles, he has given an authentic and accurate picture of Raman's Calcutta days, for he was a part of those days. He has thrown much light on this period of Raman's life and his description of Raman as a teacher is perhaps the only one of its kind available. I have used quite a bit of material from these two articles in this work, for which I am indebted to him very much. Ramdas had planned a third article. Unfortunately, this did not materialise and much rich material of the Calcutta days has been lost.

Vikram Sarabhai

Vikram Sarabhai admired Raman and had the highest regard and respect for him. In fact, he spent some time as a disciple under Raman, at the start of his research career. He was a frequent visitor to Bangalore.

The Sarabhai family are wealthy mill owners in Ahmedabad and the whole family was very attached to Raman, who had, on several

occasions, been their guest at their home in Ahmedabad. They helped him in his efforts to collect money for building the Raman Research Institute, donating generously themselves, and influencing their friends to contribute substantially to the cause.

Vikram Sarabhai was the only one in the family who took to Science. He started his scientific career as a cosmic ray researcher and became a well-known contributor in the field. Subsequently, he moved on to organising the Space Science effort in India. This has now grown into a huge, Government-sponsored research organisation. After Bhabha's death in the air crash, the Chairmanship of India's Atomic Energy Commission fell on Sarabhai's shoulders. Thus, he had the awesome responsibility, at one and the same time, of two large Government Departments, each employing thousands of scientists and engineers. Sarabhai had such fine human qualities and a superb managerial capacity that he was liked by everyone who came into contact with him, enabling him to smoothly run both organisations.

Raman was very fond of Vikram Sarabhai and encouraged him in his research. He also gave him several opportunities to conduct symposia on cosmic ray research during the annual meetings of the Indian Academy of Sciences. I distinctly remember the 1953 annual meeting held in Ahmedabad when Sarabhai and his group presented talk after talk at a symposium on cosmic ray studies in India.

Fifteen years later (1968), the Academy met in Ahmedabad to celebrate the 80th birthday of Raman. This was a happy occasion in which many Fellows participated and paid their tributes to the doyen of Indian Science. Sarabhai actively participated in this meeting and was, in fact, its principal architect. Despite his very busy schedule, he was present throughout the conference.

One afternoon, Sarabhai and Raman were seated and chatting on the lawns adjacent to the Physical Research Laboratory where the meetings were being held. I had just joined them when Raman asked Sarabhai how he was able to manage three jobs, shuttling between Delhi, Ahmedabad, Bombay and Trivandrum and overseeing the work of several huge organisations. Sarabhai explained his

schedule. Raman bluntly said: "Vikram, this is too much for any person. One of these days you will croak in the plane. Don't do this. I sincerely advise you." Vikram laughed it off, but what Raman said came true. Sarabhai suddenly passed away in the hotel where he was staying in Trivandrum on December 30, 1971. He was in Trivandrum on an official visit to the Space Science organisation. His death was apparently due to a severe heart attack.

S. Venkateswaran

Venkateswaran is an outstanding example of a part-time worker who, after a gruelling full-time routine in a Government job, out-did many whole-time researchers by working on research for more than a decade in the evenings and late into the night, on holidays and during leave periods. It was an extraordinary display of dedication and devotion to research.

He joined the Association in Calcutta as an overtime worker in 1923 and began a series of remarkable investigations on the hitherto unexplored problem of molecular scattering of light in aqueous solutions of acids and other compounds, and, later, in pure liquids. He won the M.Sc. and, later, the D.Sc. of the Madras University, submitting dissertations covering his many important research papers. He played an important part in the discovery of the Raman Effect by bringing to the notice of Raman the rather conspicuous 'so-called fluorescence' exhibited by pure, dry, distilled glycerine. This study created the urgent need to explain this 'feeble fluorescence' and, shortly afterwards, led Raman to the discovery of the Raman Effect.

Amidst his researches, this indefatigable worker found time to take his Bachelor's degree in Law. He later joined the Patents Office in Calcutta. The creation and development of the Trade Marks Registry in India was entirely due to Venkateswaran's imagination and drive. Towards the closing years of his career in government service, he not only organised the Trade Marks Registry on an all-India basis, but also took charge of both the Patents and Trade Marks Offices. Venkateswaran's example of assiduous striving and achieving against the greatest odds is indeed an inspiring one.

Raman and Venkateswaran kept in touch with each other long after the Calcutta years and the latter visited the Raman Institute a few times. Raman used to stay with Venkateswaran during his sojourns in Bombay, in his flat in Tulsi Vihar, in the fashionable Marine Drive area. Raman used to talk in glowing terms about Venkateswaran's scientific and other abilities and the latter, in turn, had a profound respect for Raman.

K. Hanumanthayya

Hanumanthayya, who succeeded K. C. Reddy as the Chief Minister of the State of Karnataka, was a colourful personality in the political arena of the state. Hanumanthayya, who had grand designs to beautify Bangalore, contributed substantially to the development of Bangalore City. The building which houses the Legislature at present, the *Vidhana Soudha*, is a monument to his genius.

He was very fond of Raman and the two used to meet quite often in those days. One such occasion was when Raman sought his help in connection with what was called the Gopal Rao Trust. The Gopal Rao affair is well known to Bangaloreans. Gopal Rao shot into fame as a banker and a great philanthropist during the War years. He had acquired tremendous wealth by attracting unaccounted money into his bank, for which he paid out phenomenal interest. Many prominent citizens of Mysore fell into the net and put their monies in Gopal Rao's trust, lured by the attractive interest. The Trust rapidly swelled to several crores[1] of rupees. Gopal Rao handed out huge sums of money for charities and acquired a great reputation as a philanthropist, the like of which Mysore had not known before. The *Maharaja* conferred upon him the title of *Dharmaratnakara* (Charitable). Raman was also attracted by the investment opportunity presented by the Gopal Rao Trust and invested Rs 200,000 in it; this was part of his Nobel Prize award.

Gopal Rao initially paid the promised interests, but soon ran into deep waters. The bubble burst one day and Gopal Rao went into

[1] One crore=Ten million

bankruptcy, the investors losing all their money. It is narrated that when it became known that Raman too had lost money, a reporter approached him for his comments and got this priceless one: "That man deserved the Nobel Prize for cheating!"

The Government later intervened and froze the left-over assets for equitable distribution among the creditors. This dragged on for years. Hanumanthayya, who entered the picture as the Chief Minister of Mysore, had a say in the distribution of these assets. Raman approached him to get back the full amount of the money he had deposited with Gopal Rao, suggesting it be given as a donation to the Raman Institute from the frozen assets. Hanumanthayya was able to arrange this and Raman recovered the lost amount, but only as a donation to the Institute. The day this good news came, Raman was very elated and spoke very highly of Hanumanthayya. Later, Hanumanthayya visited the Institute regularly and Raman and he became good friends.

Prime Minister Nehru and C. V. Raman, with K. Hanumanthayya, Chief Minister of Karnataka, in the centre. Picture taken at the Residency in Bangalore circa 1957.

Mirza M. Ismail

Raman had many admirers, some enemies and a few friends at his level. Sir Mirza was a friend and well-wisher who helped Raman in many ways. Raman had deep regard for Mirza Ismail and admired his taste and abilities. The latter visited the Raman Institute only once, but Raman was so happy to have him on that occasion.

Mirza Ismail was *Dewan*[2] of the princely state of Mysore at the time Raman was having a trying time with the governing council of the Indian Institute of Science. That body wanted to remove Raman from the Institute, but this was avoided by the intervention of a few influential people. According to one version, Mirza Ismail got the *Maharaja* of Mysore to convince the Viceroy to stop the extreme action that the council was planning against Raman. As result of this, Raman was allowed to continue as Professor of Physics, though he was relieved of his post as Director.

Mirza Ismail liked Raman's forthrightness and saw in him a genuine scientist endowed with a colourful personality. Mirza Ismail himself was a strong and decisive personality like Raman; his love of Nature and his aesthetic sense were well known. He was behind the beautification of Bangalore and Mysore, both known today as garden cities. No one could fail to notice the grandeur of the gardens, the majestic buildings and the numerous parks and fountains in these two cities in Karnataka.

Mirza Ismail had a regal bearing and fine tastes and Raman matched them with his colourful personality, ready wit and keen aesthetic sense. Naturally the two men became very fond of each other and remained good friends throughout their lives. Mirza Ismail's only connection with science, however, was when he inaugurated the Indian Academy of Sciences in 1934.

Yehudi Menuhin

Menuhin, the famous violinist, was a frequent visitor to India as he had a great liking for Indian music. He had been a child prodigy who was acclaimed a genius by Albert Einstein.

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[2]Prime Minister

Menuhin came to Bangalore and called on Raman. I distinctly remember this visit; for Raman wanted the violin he had kept in his office to be taken out and given a thorough cleaning. He wanted the instrument in a presentable condition in case he was able to persuade Menuhin to play it.

Menuhin arrived and was shown round the Institute by Raman. He knew about Raman's research on the violin and they talked about it. Raman asked Menuhin if he would like to play on the violin and said that he had kept the instrument ready. Menuhin however, was not inclined to play and smoothly evaded the issue. Nevertheless, it was a memorable visit, Raman enjoying Menuhin's company.

G. D. Naidu

G. D. Naidu, a famous industrialist from Coimbatore, was a great admirer of Raman. The admiration was mutual. Naidu was a genius; though not a formally trained engineer, he was a superb designer of machinery. He had a great fascination for Germany and German things. The story goes that he visited Germany several times and some companies he visited there were so impressed with his often brilliant suggestions that they incorporated them in their products.

Naidu was a self-made man, very clever, known for his tenacity as well as for his eccentricities. He loved playing practical jokes, particularly on Income Tax officials. He made razor blades 'to last a lifetime' and distributed them for testing. I have seen, in the Institute, some of these blades presented to Raman by Naidu. They apparently were testimonials to his word, but the idea did not prove to be a commercial success. Naidu used to experiment in plant breeding and evolved a papaya which yielded extra-large and very sweet fruit. Naidu and Raman had a great liking for each other and Raman always spent time with Naidu whenever he visited Coimbatore. Naidu came just once to the Institute and Raman proudly showed him his collections.

G. D. Naidu presented Raman a steel wire recorder for recording speech and music. This machine was the precursor of the modern tape recorder. The machine worked well and I used it once to record

the talk given by Raman to the Science Congress Session in Bangalore in 1952. This particular talk was on Raman's theory of lattice dynamics and was delivered in front of a huge audience, which included such distinguished physicists as Rudolf Peierls and G. Wentzel, the foreign invitees to the Congress that year.

Pandit Jawaharlal Nehru

The visit of Prime Minister Jawaharlal Nehru in 1957 was a memorable occasion for all of us. The Prime Minister had come to Bangalore, accompanied by his daughter, Indira Gandhi, and his two grandsons. Mrs Gandhi came to visit the Raman Institute and Raman gave her the conducted tour. She must have been under 40 at the time and looked very beautiful and charming in her saree. Raman was in high spirits and a jovial mood as he explained to her the beauty of crystals, luminescent minerals and the gems in his collection. After the visit to the museums, he took Mrs Gandhi to the first floor portico and showed her the distant Nandi Hills and the panoramic view in front. In parting, he said: "You must be tired now, after this walk up and down. You better return to the Residency and have some rest." Then, as an afterthought, he added, "Tell your Papa about what you saw and ask him to visit my Institute". That same afternoon there was a call from Government House and the Prime Minister's secretary told Raman that Nehru would like to visit the Raman Institute the next morning if it suited Raman. The latter enthusiastically agreed and everything was prepared for the reception. At the appointed time, Prime Minister Nehru, immaculately dressed in a long brown coat and a white achkan, arrived with his entourage. Raman gave Nehru a warm handshake and welcomed him. My daughter Geetha, eight years old at the time, presented Nehru with a bouquet of roses and the Prime Minister beamed his appreciation. Raman gave him a beautiful rose, which Nehru fixed in the buttonhole of his coat; Nehru loved wearing a fresh rose in his buttonhole. He looked absolutely charming and relaxed and made inquiries about Raman as well as Lady Raman who was standing nearby. Then Raman conducted the party upstairs and showed Nehru the museums, the library and the

lecture theatre. At the library, Raman introduced all of us to the Prime Minister who warmly shook hands with each of us.

At the lecture theatre, Raman delivered a fifteen minute lecture to the Prime Minister about the necessity of having an endowed chair to ensure the future of the Institute; he suggested the Government of India could help in this by instituting a special endowment fund of Rs 1 million. After Raman finished, Nehru got up, faced Raman and said: "Raman, why do you worry about the future of your Institute? The Government will gladly take care of it." To this Raman replied: "Sir, who can predict the fate of politicians and what they say? I want an unconditional commitment from you now. I certainly don't want this Institute to become another Government laboratory." Nehru smiled and moved on without further comments. The rest of the visit went off very well and they parted company cordially.

Raman was somewhat disappointed, for he thought that his appeal to the Prime Minister would produce results then and there. He knew, of course, that even the Prime Minister could not make such commitments, for he was answerable to Parliament. Raman asked me if his remarks to the Prime Minister were too strong. I felt they were and told him so, although Nehru did not take them amiss. Raman said later that he was not afraid of anyone, not even the Prime Minister, and that he had meant one hundred per cent what he had said. Raman was a fearless soul and when something close to his heart was at stake he could be far from diplomatic. This was a trait he could never overcome and it caused him nearly all his problems.

Nehru later sent a note to Raman stating how invigorating it had been to visit Raman and how much he had enjoyed the visit.

Sri Prakasa

Sri Prakasa, Governor of Madras State for several years, came from an illustrious family of scholars from Uttar Pradesh. His father, Sri Bhagwan Das, was a scholar of repute who had been conferred the title *Bharat Ratna*, the highest award that can be conferred upon a citizen of India.

During a visit to Bangalore, Sri Prakasa called on Raman. The Institute had just then started functioning and essential supplies, such as water, had barely arrived. The Governor's party drove into the Institute in all its pomp to be warmly received by Raman.

After conducting the Governor round the museums, Raman was about to show his memorabilia to Sri Prakasa when the Governor wanted to use the toilet. Raman led him into the private bathroom attached to his office. After using the toilet, the Governor found to his consternation that there was neither water nor toilet tissue in the bathroom. Bangalore water supply in those days was notorious for its unreliability and inadequacy, and even after 40 years the situation still remains the same. An overhead tank was under construction at the Institute to take care of the situation. The poor Governor frantically appealed to anyone outside to pass him some water. Fortunately, Raman was resting in his office and heard the Governor's appeal. He was quite agitated about the Governor's predicament and sought our help. The ADC to the Governor was running here and there, but could do little in a place unfamiliar to him. However, Raman thought of a solution; he decided to pass in the mud pot usually kept in his office with drinking water. Raman called out to the Governor and said: "I say, Sri Prakasa, I have kept a pot of water just outside the door. Help yourself to it." The Governor took in the pot quickly and, after a few minutes, came out smiling. Raman continued with the rest of his plans, before giving the Governor a hearty send off.

After this incident, the contractor who was installing the overhead tank was called in immediately and asked to instal it as expeditiously as possible.

M. Visvesvarayya

Sir M. Visvesvarayya was an eminent engineer from Karnataka. He was responsible for starting many industrial projects in the old, princely Mysore State. The Bhadravathi steel project and hydroelectric projects in the state were his creations.

Both a visionary and a man of action, he served as Dewan in Mysore State under the *Maharaja*. He lived to be a centenarian and led a disciplined life till the very end. He was always dressed immaculately, in a three-piece suit and a *Jari* turban.

Raman and Visvesvarayya must have seen each other often when the latter was in active service, but during my days in the Raman Institute he came only once to visit the Institute and that too towards the end of his life. He had become so frail, he had to be literally carried by two people. He wore formal dress and was in excellent possession of his mental faculties. Raman received him and talked to him about the Institute and his interests at that time. Visvesvarayya commented: "Raman, you should also do something useful to society. Your scientific research should benefit people at large." This statement was, of course, not relished by Raman, but he did not counter it. Later, however, he told me that "that decrepit old man need not have come all the way to tell me this". Soon after this visit, Visvesvarayya passed away. Mysore lost an illustrious son who had done so much for the industrialisation of the state.

The *Maharaja* of Mysore, Jayachamarajendra Wodeyar

Raman had a special liking for the *Maharaja* of Mysore. The *Maharaja*, who had supported Raman in many ways, had a great affection for him and appreciated his achievements. It was he who donated eleven acres of land for building the Raman Research Institute, when Raman approached him with his dream of a research institute. He again donated another four acres of valuable land adjoining the Institute, when Raman wanted space to build a residence for the Director of the Institute.

Raman valued real estate highly and invested quite a bit in it. He always came out on the right side, and the richer for them, in his real estate dealings. He had once bought several acres of land in Alwarpet, Madras, at a time when the value was low. This property had appreciated a thousand-fold when he sold it, bringing nearly a million rupees to his Institute. The *Maharaja*'s land gifts gave Raman what he most valued and prized.

Raman was an individual honoured by the *Maharaja* and, therefore, had a place in the Court of Mysore. When Mysore was a princely state, during *Dasara*, a special *Durbar* was a regular feature and Raman was always an invitee. He had to present himself in *Durbar* dress and pay homage to the *Maharaja*.

After independence, the princely states vanished and Mysore became Karnataka state with a popular elected Government. Jayachamarajendra Wodeyar accepted the Governorship of Madras and served as its Governor for over five years. It was during this term that he once came to visit Raman at the Institute. Raman spread the red carpet and accorded a very warm welcome to the former *Maharaja*. The *Maharaja*, a very impressive figure, looked majestic in his turban and long coat. He was also a scholar of repute and his interests spanned a range from philosophy to music. Raman had tremendous regard for His Highness and I think it saddened him to see the passing away of an era in Indian history which had been so colourful and supportive of culture.

Marshal Bulganin and Nikita Khrushchev

Many foreign dignitaries used to visit the Raman Institute. One of these visits arranged for 1955 did not take place. Marshal Bulganin and Khrushchev, President and General Secretary of the USSR respectively, were scheduled to visit the Raman Institute, but the plane carrying them was delayed for some reason and this necessitated cancellation of some of the engagements.

Raman had a natural aversion for communism and communist philosophy but agreed to the visit, perhaps out of consideration for the Chief Minister of Karnataka who had requested him to make arrangements for it. He said: "After all, they are leaders from a great country and we should welcome them". Accordingly, welcome festoons were hung on the road leading to the Institute and Raman awaited the visitors with his retinue. Just half an hour prior to the appointed time there was a telephone call from the Residency, to the effect that the visit had to be regretfully cancelled due to the late arrival of the dignitaries. Raman was furious and his spirits drooped.

He ordered the festoons removed, saying: "Tear down the festoons. It is good anyway we don't have to welcome the arch communists into my Institute."

Years later, Raman was awarded the Lenin Peace Prize and went to Moscow to receive the award. The prize involved a substantial sum of money. Raman did not relish accepting the award, but he argued that the Rs 150,000 that came with it would be useful to the Institute. Raman had decided to give the prize money to the Institute. How Raman got involved in this is not quite clear, but a retired Major General, Sokhey, had something to do with it. The General, who had been an earlier recipient of the Peace Prize, had once visited the Raman Institute. This visit, I believe, set the ball rolling; the General might have obtained Raman's tacit approval to go ahead with his proposal to nominate Raman. The award was announced soon after, and Raman went to Moscow as an honoured guest of the Russian Government. On his way, he visited Hungary and met Heyrovský, the famous electrochemist, in Budapest. Raman spoke very highly of the scientist who invented polarography and enjoyed the visit to his laboratory.

Raman and Lady Raman with Dr Zdenek Nejedly, Minister of Culture and Education of Czechoslovakia, Prague, 1958. (Photo Courtesy of *The Hindu*)

The award ceremony in Moscow appears to have gone off all right, but Raman was not happy with the visit. Apparently, some remarks concerning the discovery of the Raman Effect were made during the award ceremony, suggesting that the Russian scientists Landsberg and Mandel'shtam had made the discovery simultaneously and should have received equal credit. Raman resented this and remarked later, "I should not have accepted the award". However, all was soon forgotten and he dismissed the episode from his mind.

Max Born

Max Born figured in a very significant way in both the scientific and personal life of Raman. I have already mentioned Max Born's visit to Bangalore in 1935 and his return to England in six months, after his permanent appointment to a Chair at the Indian Institute of Science was aborted. Here, I would like to add some details about Max Born, his experiences in India, and the scientific controversy which later cropped up between him and Raman, all of which happened while Raman was still at the Indian Institute of Science.

Max Born was born in Breslau in Germany on December 11, 1882, and he died on January 5, 1970, at the age of 88, in Göttingen, the town which, forty years before, had become the Mecca of Modern Physics through his work. He was the father of a whole generation of physicists and was held in deep veneration by his pupils. Five Nobel Prize-winners were nurtured by him: Werner Heisenberg, Wolfgang Pauli, Enrico Fermi, Paul Dirac and Maria Goeppert Mayer.

Born's father was an anatomist and embryologist. Born himself, though conscious of both an inclination and talent for mathematics at an early age, first studied law, philosophy and astronomy before turning to physics. Göttingen, Zürich, Cambridge and his home town of Breslau were milestones in his scientific life. In 1907, he secured his doctorate at Göttingen with a thesis on 'The Stability of Elastic Strips and Wires', a paper which received a special award from the faculty. Two years later, he became qualified to lecture, with a

paper on 'The Relativistic Electron'. In 1912, he went to Chicago to give lectures on the theory of relativity. He went to Berlin in 1914 in response to an offer by Max Planck and was appointed Assistant Professor of Theoretical Physics there in 1915. He became a Professor in Frankfurt-on-Main in 1919, before moving on to Göttingen in 1921.

In Berlin, he was a close friend of Planck and Albert Einstein. Göttingen was a great centre for theoretical physics in those days, with Born the central figure. At that time, he believed that so mathematical a science as theoretical physics could really be pursued only for the sake of pure knowledge and his interest was, therefore, devoted "constantly more to the philosophical background of science than to specific results". He did not fail, however, to produce over 300 papers and 20 books in his lifetime and established himself, along with Einstein and Planck, as the most prolific interpreter of newly discovered physical phenomena that were only just then being perceived in outline.

To Born we owe the realisation that the components of the atom, the protons and electrons, do not move — contrary to all previously known natural laws — in precise, mathematically predictable courses, with the obvious statistical consequences. This was admittedly a shock for the classical physicists and their notions. Even his friend Einstein commented sceptically, "God doesn't throw dice", but Born was proved right. In 1926, together with Heisenberg (his former assistant) and Jordan, he succeeded in marshalling a number of Heisenberg's previous results to form a comprehensive theory of atomic phenomena in the science of quantum mechanics. He was fascinated by the structural configuration of the atoms in crystals.

In 1933, at the age of 50, he was placed 'temporarily' on the retired list by the Nazis, on account of his Jewish ancestry. Two weeks later, he left Germany. He went to England, then spent a short time in Bangalore, in India, before finally receiving a professorship in Edinburgh, where he lectured until his retirement in 1953 — "a congenial assignment in Darwin's footsteps" was his own comment. In 1954, he returned to Germany — to the Federal Republic — and

in the same year, was awarded the Nobel Prize. He was content to remark somewhat coolly about this news: "I haven't really made any specific discovery of immediate economic use, like nylon or neon lighting. I have only evolved a pattern for thinking." He was not quite so cool in his assessment of the actual and potential role of Science in human life. He issued a public warning, for instance, against nuclear armament, and his scepticism continued to increase. The development of the atom bomb horrified him. He once said:

> "Although deeply devoted to Science, I cannot help feeling that it is a force so contrary to historical evolution and tradition that it can be absorbed by our progressive civilisation. The political and military cataclysms and the total collapse of ethics that I have witnessed in the course of my life are by no means symptoms of a temporary social reverse; they are the logical consequence of the ascendancy of Science, which is actually one of the greatest achievements of human intellect. If this is so, it is the end of Man's career as a free, responsible being."

On space travel, his final judgement was: "A triumph of the human brain, but a tragic failure of reason." He even went to the length of saying: "It would appear that Nature has failed in her attempt to bring forth a thinking being on this planet." Such dicta were intended not only to express doubt concerning the proper use of Science in human hands — and competent hands at that — but were also uttered as food for thought. Although Max Born believed that scientists did not "differentiate sufficiently between enthusiasm for their work and the latter's usefulness to mankind", he hoped to the last that he might be mistaken.

He based his ideas on the 'luxury of conscience' (as one of his books was entitled), and was prepared to believe that, in spite of the nuclear bomb, the science of physics furnished a suitable model for the peaceful settlement of conflicts. He said: "The world, which is so keen on using the achievements of physics for the purpose of mass destruction, would be better to study the reasoning methods used in physics, which have repeatedly served to elucidate and reconcile apparently irreconcilable theses."

Raman wrote to Max Born asking him to suggest the name of a young theoretical physicist for appointment at the Indian Institute of Science, but later invited Born himself to spend six months lecturing in Bangalore.

Born and his wife arrived in Bangalore in the autumn of 1935. Born later remembered: "In Bangalore we were received by Lady Raman, who took us to our 'bungalow', which was actually a big two-storey house with numerous rooms. We had a large garden with beautiful trees and flowers. The Raman family lived in a similar house just across the road."

"We liked Lady Raman right from the beginning. Her husband was absent and appeared a few days later. We were fascinated by his appearance and talk. Hedi said he looked in his Indian dress and turban like a prince from the *Arabian Nights*."

Max Born gave a series of lectures, which were attended by Raman and his staff, by the heads and assistants of some related departments, and by a few post-graduate students. These lectures were about the theory of crystal lattices, crystal optics and the Raman Effect. B. S. Madhava Rao, a well-known mathematical physicist of Bangalore who interacted with Born, has spoken in glowing terms about Born's scientific mind and his depth of mathematical understanding. Born, for his part, was struck by the scholarly enthusiasm of a pupil of Raman, Nagendra Nath. Born later recalled: "I had innumerable discussions with Raman and his collaborators on their experimental work, mostly optical problems connected with the Raman Effect. There were also several violent disputes between Raman and me about his theoretical ideas. But, on the whole, we were on friendly terms."

In general, the Borns, particularly Born's wife Hedi, seem to have enjoyed their sojourn in Bangalore. Born said: "Life in India was very pleasant for us. Hedi enjoyed it even more than myself. She met a Swami of the Ramakrishna order, and they became great friends. He told her that she had been an Indian woman in an earlier incarnation, because she understood Indian spiritual life so well."

Raman decided to initiate the offer of a permanent position to Max Born at the Indian Institute of Science and Hedi seems to have pressed her husband to agree to it. Born "had no other job". So he was willing to accept Raman's offer, if he could obtain the consent of the Council of the Institute. This is where Raman ran into deep trouble, the whole episode ending in a fiasco. Born felt that Raman had not been tactful, and in his enthusiasm to get his appointment through, had taken several inappropriate steps. Further, an English Professor on the faculty had made several unpleasant remarks about him, and the humiliating thing about it was that Born had to listen to them. Raman had apparently insisted that Born should also attend this faculty meeting, thinking that everything would go according to his plan. Raman evidently did not expect such an unpleasant turn of events at the meeting.

After this, the Borns decided against staying in India and began preparing to return to England. Born thought that the aftermath of this unpleasant episode led to Raman's resignation from the Directorship of the Institute. He also added: "I presume that this regrettable result of my visit rankled in his (Raman's) mind, for later a difference of opinion about scientific questions developed between us. Otherwise, the bitterness of his attacks against me and his personal behaviour are hard to understand." The scientific dispute concerned lattice dynamics and deserves describing in some detail.

The Lattice Dynamics of Raman and Born

Lattice dynamics is a topic in theoretical solid state physics concerned with the vibrations of the atoms in a crystal lattice. A crystal is an ordered assembly of atoms or molecules held together by interatomic forces. The atoms in a crystal lattice are constantly vibrating about their mean positions, very much like the vibrations of a stretched string, and these vibrations are governed by the symmetry properties of the crystal and the number of atoms in the unit cell. The unit cell is the smallest repetitive entity of the crystal. These atomic vibrations can be determined by Raman spectroscopy.

If a crystal such as diamond is placed in a laser beam and the scattered light is analysed by a spectrometer, a sharp Raman peak down-shifted in frequency by 1332 wavenumbers from the exciting laser line is observed. Such a simple Raman spectrum is because of the high symmetry of the diamond lattice which has only two carbon atoms per unit cell. In crystals of low symmetry with many atoms in the unit cell, there will be a multitude of Raman peaks. According to a simple rule, the number of vibrational modes is equal to the number of atoms p in the unit cell multiplied by the 3 degrees of freedom allowed for each atom, minus the 3 pure translational degrees of freedom of the unit cell, which gives $(3p - 3)$ vibrational modes. For the case of diamond, $p = 2$. Therefore, three vibrational modes are got from the above equation and it turns out that these three modes have the same frequency in diamond.

In modern solid state physics terminology, these vibrational modes would be described as zone-centre optical phonons because they have an infinite wavelength. However, in a crystal, the zone-centre modes are not the only vibrational modes and, in order to obtain the whole frequency spectrum, all the normal modes of the crystal lattice have to be taken into account. The controversy between Raman and Born had to do with the enumeration of these modes and, in particular, the definition of a normal mode.

Raman took the view that normal modes are only those in which equivalent atoms in adjacent unit cells have the same amplitude, and must either vibrate in phase or out of phase. To enumerate these modes, Raman considered a part of the crystal called the supercell, which he obtained by doubling the unit cell along their edges. This supercell is eight times larger than the unit cell and hence will have $8p$ atoms. Raman proposed that this supercell would have $24p$ degrees of freedom associated with it, three of which would represent the translational degrees of freedom of the supercell as a whole, giving $24p - 3$ normal modes. Because of the crystal symmetry, modes can become degenerate in frequency and reduce to less than the above number. For the case of diamond, with $p = 2$ atoms, Raman's theory gives 45 normal modes which reduce to nine distinct

frequencies because of the high crystal symmetry. Raman showed that these are associated with the vibrations of the octahedral and cubic planes of the crystal. However, this view, that the normal modes consist only of a small number of discrete frequencies, is in disagreement with the widely held Born–von Karman theory of lattice dynamics.

According to the Born–von Karman theory, the normal modes are almost infinite in number in a finite crystal and have a wave-like feature, giving a frequency spectrum that is quasi-continuous. The theory uses a boundary condition known as the cyclic postulate. The neutron dispersion relations in crystals strongly supported the Born–von Karman theory. Yet, Raman violently disagreed with the Born–von Karman theory and never reconciled himself to it even when the whole world was against his theory.

Raman's conviction was based on light-scattering spectroscopy conducted in his laboratory at the Indian Institute of Science, which only revealed those components that appeared with strong intensity in the Raman spectrum. He took only these strong features and built a lattice dynamical theory. On the other hand, the more powerful inelastic neutron-scattering measurements have clearly established the quasi-continuous nature of the vibrational spectrum. Indeed, recent laser Raman scattering experiments on diamond itself have revealed that the peaks identified by Raman and his collaborators as discrete frequencies are superimposed on a continuum of frequencies, again supporting Born's theory.

In the latter theory, the normal modes are visualised in terms of waves, the distinct wavevectors possible being distributed inside the Brillouin zone. Of these, waves associated with zone boundaries would have vanishing group velocity and would, in fact, correspond to the vibrations of the type Raman visualised. In other words, out of the large number of wave-like normal modes permitted in the Born theory, Raman's theory focussed attention on a selected subset, which are primarily characterised by vanishing group velocity. Born pointed out very clearly the fallacies in the theory proposed by Raman.

Raman came back to this subject again and again, emphasising that his was the correct view. He severely criticised Born, Debye and others in published papers and in talks. I remember his talk on lattice dynamics delivered before a large audience during the Science Congress in Bangalore in 1952. Raman spoke for an hour and forty-five minutes and denounced Born in strong language. Peierls, who was in the audience, was very upset about Raman's remarks and wanted to question him. He was, however, not given adequate time to say much and the meeting ended rather abruptly, on an unpleasant note. Raman lost his temper and thereafter did not come to any of the sessions.

Born mentions two meetings with Raman after this controversy. The first of these meetings was in Bordeaux in 1948, the second in Lindau. Born wrote:

> "He (Raman) received an honorary doctor's degree, but the same degree was also conferred upon me. I am sure the French colleagues did this to demonstrate that in the dispute about lattice vibrations, not Raman, but I was right. At the first reception in Bordeaux we greeted each other very cordially and had a lively talk.
>
> Then Raman abused some theoretical physicist because he had done experiments which Raman regarded as poor. I replied, 'But, my dear Raman, what about the other way round, when experimentalists venture to make theories?' or something like that. Though he first remained quite friendly, he later became furious and said to Hedi, his neighbour at the banquet, that I had given him deadly offense and that he would leave the conference. She had great trouble in appeasing him, but during the whole congress he was nervous, excitable and aggressive....
>
> The second time, we met Raman at one of the Lindau meetings of Nobel Laureates. He was sitting at the next table in the dining room of the Schachen Hotel, greeted us in a very friendly manner and talked in his lively manner, moving from one table to the next. But the next day his attitude had changed. He avoided us and went out of the way when we met in the house or garden. He must have suddenly remembered that I was his 'enemy'.

Actually I never was. I still admire his fascinating personality, his devotion to science and research. It makes me sad to think that by inviting me to India and trying to keep me there permanently, he brought himself into a precarious situation, and had to give up his leading position at the Institute of Science. But I cannot see that I am to blame for this misfortune. Nor can I accept a scientific theory which I regard as wrong. Hedi and I regret all this and particularly the split between us and Lady Raman, whom we loved dearly."

Raman and Max Born were great scientists in their respective fields and were strong personalities. They started off as good friends, but once they got involved in a controversy, egotism overpowered all rational behaviour. All this goes to show that scientists are also human beings and prone to err as much as the common man. On Raman's part it needed tremendous courage and conviction to oppose Born in theoretical physics. Raman was, of course, proved incorrect, but the point is he honestly believed that his spectroscopic results could not be explained otherwise. In any case, the controversy made lattice dynamics a lively subject for a decade and with the advent of neutron spectroscopy it acquired a new experimental flavour.

It is interesting to note how similar the attitudes of Raman and Max Born were on the question of the misuse of Science for mass destruction and space travel. (Compare Raman's IIT Convocation Address given later and Born's attitudes mentioned in this section.)

C. Rajagopalachari

Rajagopalachari (C.R.) and Raman were contemporaries in the Indian scene, but they pursued different interests in life. C.R. was an astute politician who rose to become the first Governor General of India, after Lord Louis Mountbatten stepped down. Raman rose to the pinnacle of physics and was the most colourful personality in Indian Science. Different motivations drove these two illustrious sons of India to greatness, but they were the products of a common culture which nurtured excellence and intellectual pursuits. C.R. in later life took to writing and made a great contribution to religious literature

in Tamil. C.R.'s writings had a special quality in them, for he used simple language and used appealing paradigms to make the greatest truths understandable to the common man.

Raman and C.R. were forthright in their views and expressed them clearly. While C.R. was quite subtle, Raman often used powerful language. On one occasion, C.R. had this to say of Raman: "Raman is like a brilliant cut diamond. If you rub it on the wrong side, it will cut your finger." Such was C.R.'s subtlety.

The language issue in India has given rise to some of the bitterest controversies, and the issue rears its ugly head even today. In the Fifties, it was a hot issue and Prime Minister Nehru appointed a commission, with Dr Kher as its Chairman, to elicit public opinion on the issue from all sections of the society, including prominent individuals. When the Kher Commission came to Bangalore, Raman was invited for his comments. In no uncertain terms, Raman told the commission about the disadvantages of replacing English with Hindi as the national and official language of India. Raman said, "Sir, you will be putting the country 100 years behind by adopting Hindi". He added with a bit of sarcasm, "If you want to give up English, I would vote for Sanskrit, which is our ancient language". This statement of Raman appeared in the newspapers. The next day Raman received a postcard from C. R., which said: "Raman, I congratulate you for your forthright views on the language issue to the Kher Commission. Well said." Raman was elated at receiving this acclaim from this distinguished son of India.

Mahatma Gandhi

In 1936, Mahatma Gandhi visited the Indian Institute of Science and met Raman. Gandhiji was accompanied by Sardar Patel, Kasturba Gandhi and Mahadev Desai. Raman took them round the Department of Physics, explaining in his unique, inimitable style, studded with good humour and jokes, the scientific work going on at the time.

It is interesting to note the reactions of a distinguished scientist like Raman on issues that have no direct relation to Science and in

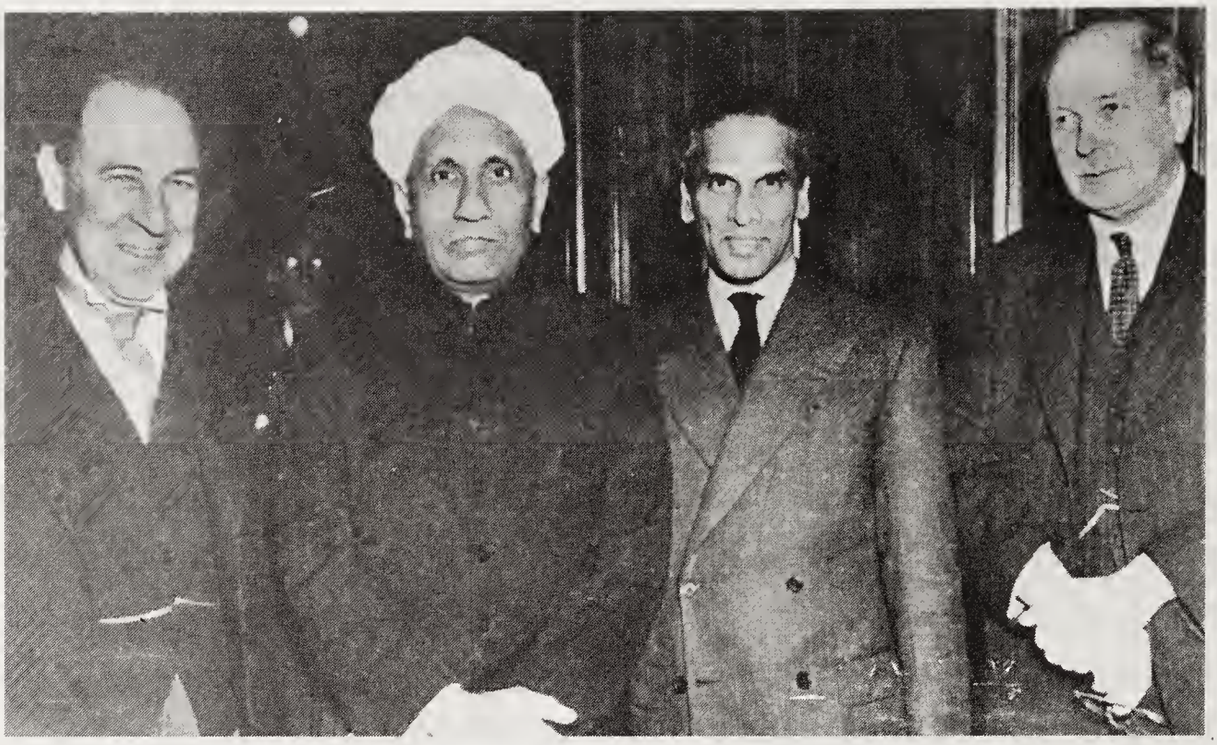
regard to so eminent a person as Gandhi. On one occasion, when Raman was requested to write about Gandhi, he wrote thus:

> "Politics and Science are as poles apart and as I never attend political meetings or make political speeches, the chances of my ever having met Gandhi might seem to have been infinitesimal. Nevertheless there have been quite a few occasions on which I have met and spoken with him. These occasions remain vividly impressed on my memory, and some of them may be worthy of being put on record.
>
> One such was in the year 1945 when I was staying at Bombay in the residence of the Sarabhai family in Nepean Sea Road and was being helped by Vikram Sarabhai to collect funds for the construction of my Research Institute at Bangalore. One evening, Vikram suggested that I might call on Gandhiji who was conducting a prayer meeting on the beach sands. I waited on the outskirts of the crowd till the meeting was over and then moved forward to meet him. To my surprise, he immediately recognised me, made enquiries about me and about Lady Raman. Then he proceeded to recall his visit to my laboratory at Bangalore several years earlier and specially mentioned the demonstrations of the harmonic modes of vibration of the Indian musical drum, which I had shown him, and which had evidently impressed him.
>
> Another occasion was when he was recuperating in the hill station of Nandi, some thirty miles from Bangalore. I walked up to the hill-top in company with a Swiss scientist, who was studying the tiny organisms known as Tardigrada, which survived even when held at very low temperatures, and who specially desired to be introduced to Gandhi. We found the latter seated on the floor with several others on either side. To test Gandhi's reactions, I introduced the Swiss scientist as a famous biologist, who was investigating forms of life that could live without food and without water for twelve years! The retort came swiftly: 'When the investigations are completed, I should like to have a copy of the paper describing their results!'
>
> When Gandhi fell by the hand of the assassin, and the nation heard the news with shock and horror, I was one of those asked to record what I felt. In a few short sentences, I summed up Gandhiji's life. The substance of my comment was that he was a great humanist, interested, above all things, in the welfare of his fellow-beings."

During the meeting with the Swiss scientist (Dr Rahm), the latter apparently talked to Gandhiji about conflict in the world, warring creeds and atheism.

Raman interjected: "I shall answer your question. If there is a God we must look for him in the Universe. If he is not there, he is not worth looking for. I am being looked upon in various quarters as an atheist, but I am not. The growing discoveries in the science of astronomy and physics seem to be further and further revelations of God. Mahatmaji, religions cannot unite. Science offers the best opportunity for a complete fellowship. All men of Science are brothers." Gandhiji said: "What about the converse? All who are not men of Science are not brothers?" The distinguished physicist saw the joke and said, "But all can become men of Science".

"Science" said Raman "is nothing but a research for truth — truth not only in the physical world, but in the world of logic, psychology, behaviour, and so on. The virtue of a truly scientific frame of mind is the readiness to reject what is false and untrue. It proclaims from the house tops that there is no virtue in sticking to untruth. I think the latest biological discovery is that there is no fundamental cleavage between the life of man and the life of lower creation and that salvation lies in the perfection of the biological instinct for the perpetuation of race — the instinct to sacrifice the individual for the sake of the species." (*Harijan*, 30.5.36)



Sir John Anderson, C. V. Raman, V. K. Krishna Menon and Sir Charles Darwin at a reception in honour of Raman by the High Commissioner in London, May 11, 1948. (Photo courtesy of *The Hindu*)

President Rajendra Prasad inaugurates the Seventeenth Annual Meeting of the Indian Academy of Sciences on December 27, 1951, in Delhi. Raman is seated on the left. (Photo courtesy of *The Hindu*)

Raman in the company of Nobel Prize men at the conference in Lindau in 1956. Wolfgang Pauli singing in a jovial mood. Max Born, wearing a dotted tie, is seen on the left, first in the second row. (Photo courtesy of *The Hindu*)

Chapter IV

Honours and Awards

The awards and honours that Raman received during his lifetime were numerous. Among the earliest, his election in 1924 as a Fellow of the Royal Society, London, was significant both for his scientific career and his public image.

In September 1925, just six months after his return from America, Raman proceeded to Leningrad and Moscow to represent the Calcutta University at the bi-centenary of the Russian Academy of Sciences. He was welcomed with great enthusiasm at the centenary functions and later toured extensively, visiting the Caucusus region, Georgia and the Caspian shores. Returning to Leningrad, he visited Germany via the Baltic and later saw the lakes of Italy before returning to India.

Raman was knighted in June 1929. He was awarded the Matteucci Medal by the Societa Italiana della Scienza of Rome in 1928. In 1930, the Royal Society of London presented him the Hughes Medal for his distinguished work on optics. During the award-giving ceremony, Lord Rutherford read the following citation:

> "Sir Venkata Raman is one of the leading authorities in Optics, in particular on the phenomenon of the scattering of light. In this connection. about three years ago, he discovered that the light's colour could be changed by scattering. This had been predicted some time before, but in spite of search, the change had not been found. The

RAMAN EFFECT must rank among the best three or four discoveries in Experimental Physics in the last decade. It has proved, and will prove, an instrument of great power in the study of the theory of solids. In addition to important contributions in many fields of knowledge, he has developed an active school of research in Physical Science in the University of Calcutta."

In 1942, the Franklin Institute of Philadelphia awarded him the Franklin Medal. The citation on that occasion said, amongst other things, that the award to Sir C. V. Raman was in recognition of his many brilliant contributions to Physical Science and of his leadership in the renaissance of scientific work and scientific education that has occurred in India. The Soviet Union honoured him with the International Lenin Peace Prize in 1957.

Several Indian universities, amongst them the universities of Calcutta, Bombay, Madras, Benares, Dacca (at that time in India), Allahabad, Patna, Lucknow, Osmania, Mysore, Delhi, Kanpur and Sri Venkateswara, conferred Honorary Doctorates on him. Amongst the universities outside India, mention may be made of the University of Freiburg which conferred on him the Hon. Ph.D. degree and the University of Glasgow which conferred the Hon. LL.D. in 1930. He also received the degree of Hon. Sc.D. of the University of Paris in 1932.

He was an Honorary Member of the Deutsche Akademie of Munich, of the Zurich Physical Society, the Royal Philosophical Society of Glasgow, the Royal Irish Academy and of the Hungarian Academy of Sciences. He was an Honorary Member of Indian Science Congress Association as well as of several other Indian science organisations. He was General President of the Indian Science Congress in 1929 and was President of the Indian Academy of Sciences from its foundation in 1934 till his death. He was a Foreign Associate of the Academy of Sciences, Paris, and a Foreign Member of the Academy of Sciences of the USSR. He was an Honorary Fellow of the Optical Society of America and the Mineralogical Society of America; an Honorary Member of the Academy of the Socialist

Republic of Rumania and of the Catgut Acoustical Society of America; and a Member of the Czechoslovak Academy of Sciences. In 1961, Pope John appointed him a member of the Pontifical Academy of Sciences.

During the Indian freedom struggle, and towards the end of British rule in India, most persons who had been knighted gave up their titles in protest against the British suppression of the freedom movement. Raman did not follow suit. His argument was that he did not get the honour for political reasons or through influence; it was given to him for his scientific achievements and there was no need for him to give it back. After India became independent, the British-conferred titles and honours had no significance. But Raman was always referred to as Sir C.V. Raman.

Amongst the many Indian distinctions he received, special mention must be made of the title *Rajasabha Bhushana* conferred by the *Maharaja* of Mysore in 1935. This title, when literally translated, would read as 'The Jewel of the King's Court'. In 1954, the Government of India instituted the title of *Bharat Ratna* (Jewel of India), the highest honour of the land, and conferred it on Raman. He is the only scientist to have been thus honoured up to the date of publication of this book.

During my stay at the Raman Institute, Raman went abroad twice. Once, I think it was in 1956, he was invited to the Lindau Conference of Nobel Prizemen in Physics, at Lake Constance in Germany. After the conference, Raman went to a few places in Germany. Overall he enjoyed the trip very much. In 1958 he went to Russia to receive the International Lenin Peace Prize. This time Lady Raman went with him. At some point, Radhakrishnan, his younger son, joined them and the three travelled together. Raman was away for over a month and he asked me to take care of the affairs of the Institute during that period and deal with all matters including correspondence.

Raman's wide interests

Raman was keenly interested in geology. His knowledge of rocks and rock-forming minerals would surprise even a seasoned geologist.

He had in his museum a lovely collection of different types of granites, all of them polished to expose their structure, colour and constituent minerals. Likewise, he had specimens of limestone from all over the world. Several of these had been polished to reveal their colours and patterns. He very proudly used to show visitors polished Carrara marble slabs from Italy and Rentachintala limestone from what is now Andhra Pradesh, India. He had specimens representing sedimentary rocks, slates and sandstone. He could give a learned talk on rock-forming minerals, fossils and the age of rocks.

L. Rama Rao, a well-known professor of geology at the University of Mysore and a paleontologist, speaks of Raman so: "Any geologist who had opportunities of meeting C. V. Raman and talking to him about recent developments in any aspect of geology — as for instance, micropaleontology, which is so far removed from physics — was soon struck by his amazing capacity to follow with clear insight all that you said and he would soon follow up by putting a number of questions of a fundamental character in the field, which were most thought-provoking and immediately opened out an altogether new outlook in your approach."

A couple of years before his death, he spent a lot of time studying the geography and the geology of the Krishna Valley (in Andhra Pradesh, India) and the rivers in the region. It was known that at one time this had been an active diamond-mining area and Raman believed that there might still be more diamonds to be mined here. He wrote:

> "The river Krishna and its principal tributary, the Tungabhadra, flowing respectively in south-easterly and easterly directions, enter the area shown in the geological maps as the Kurnool formations. Further on, they meet and join up near a place known appropriately as Sangameswaram. The united stream then flows eastwards through the area known geologically as the Cuddapah formations. The actual course of the river in these formations is very tortuous. The stream exhibits a conspicuous double bend in the vicinity of the famous shrine of Srisailam. Further on, it turns sharply northwards and its path lies outside the Cuddapah formations for a short length. But the river soon returns to the area of those formations and follows a course roughly

parallel to their crescent-shaped outline. Towards the end of its course in the area, it curves round and then meets obstacles to its flow in the form of hills of considerable height and extension. As a result, the river takes a north-easterly direction in the endeavour to by-pass these obstacles and finds a gap through which the waters can flow again southwards. After passing through this gap, the Krishna flows almost due south. It then widens out as it approaches Vijayawada and, passing through another gap between high hills, flows down into the alluvial plains beyond and then to the sea.

The distance between Sangameswaram and Vijayawada by a straight flight is 178 miles. But measured along the actual path of the river it is no less than 276 miles, the difference arising from the several deviations from a straight path already mentioned. In cutting its way through the Amrabad plateau, composed of rocks of the Cuddapah system, the river passes through a great gorge about one hundred miles long.

The three rivers Godavari, Krishna and Pennar have built up in the course of ages an extensive coastal area of deposited material extending all the way from Kakinada to Nellore. This area, which is shown in the geological maps as a recent formation, exhibits a curious feature in the shape of a tongue with lateral extensions protruding towards the interior behind Vijayawada and with the river Krishna flowing through it. This feature has evidently resulted as a consequence of the flow of the Krishna towards the sea being arrested by the presence of high ground in the shape of rock formations of the Khondalite series. It is in the material thus deposited by the river before it passes Vijayawada that the diamonds carried down by it were sought for and found in past years.

The first volume of the *Journal of the Hyderabad Geological Survey* published in the year 1929 contains a compilation of all available information on the ancient diamond mines in the area. The maps appearing in this publication indicate the locations not far from the present course of the Krishna river where the diamonds were taken out. All of them were on the northern side of the river, namely Partial, Atkur, Munnaluru, Mogaluru, Koduvatkallu and Ustapalli, with one very significant exception, namely, Kollur. This last was on the right bank of the river where it takes a sharp turn to the north-east by reason of the presence of a range of hills blocking its flow eastwards. Kollur

appears to have been a highly productive locality. It was visited by Tavernier who described the surface workings and stated that some 60,000 people were engaged in the mining operations at the time of his visit.

An intensive and prolonged exploration of any particular locality for diamonds might be expected to result in its ceasing to be productive, sooner or later. This is indeed the actual situation, and the fabulous wealth these mines produced is now only a memory. It is of course possible that several less promising locations were left unexplored, and it is also possible that methods of mining which go down to deeper levels might produce results. An inspection of the maps suggests that the course of the river Krishna above Vijayawada has shifted progressively southwards as the result of the deposition of the material which it brought down, and hence the exploration of areas further removed from its present course, and especially of the areas silted over by the streams flowing into it laterally, might conceivably prove to be profitable. But the chief interest attaching to the subject of the diamonds found in the past in the Krishna valley is in the problem of locating the original source of diamonds and exploiting these original sources to the fullest practicable extent.

The long and tortuous course pursued by the river between Sangameswaram and Vijayawada lies for the most part in what are recognised geologically as the upper Cuddapah formations, and only a small part of the same lies within the formations of lesser age known as the Kurnools. The actual facts of the case suggest that the diamonds deposited in the lower reaches of the river were a part (and naturally only a very small part) of the material scooped out by the flood waters from the floor and walls of the gorges excavated by them and deposited where the flow was arrested. Whether this action was confined to any particular stretch or stretches of the length of the river or whether it extended over the whole or a greater part of its entire course can only be surmised and must await determination by a careful examination of the exposed areas of the river gorges.

It should be emphasised that the Krishna valley lies much further north than the areas bounded on the west by Lattavaram and Guntakal and on the east by Dhone and Gooty and including especially the well-known locality of Vajrakarur, where there were diamond workings in the sixteenth and seventeenth centuries. The geological maps

> show that the areas mentioned lie outside the Cuddapah formations, and there is therefore no reason for assuming that the circumstances which led to diamonds being found in these areas at or near the surface of the earth have any bearing on the problem of the original source of the diamonds found in the Krishna Valley. Further, in view of the great age of the Cuddapah formations and the absence of any evidence of volcanic activity in the regions traversed by the Krishna river, there is nothing to suggest that the diamonds in the valley were thrown up and made accessible to erosion by the flow of the river by any such activity in the ages subsequent to the laying down of those formations.
>
> The whole purpose of this article is to indicate that the history of diamonds in the Krishna valley need not be treated as a closed chapter having only a historic interest and that, on the other hand, it may well prove to be a subject of practical importance at the present time if pursued vigorously but with the necessary circumspection."

It is unbelievable that a physicist could have written so candidly and knowledgeably about the geology of a particular region of India!

The lectures which Raman delivered before he wrote this article were received with great interest in Andhra State and it was evident to many who listened to him that he had worked on the subject with great concentration and with deep personal involvement. It is a typical illustration of the intensely devoted manner with which he always tackled whatever subject he chose to study. He was never content with a superficial examination, but always raised doubts in regard to basic assumptions which others did not dare question.

Raman had a lively interest in meteorology and during the Indian Academy of Sciences' annual meetings he organised many symposia and lectures on various aspects of meteorology. I remember very well the symposium on the 'Physics of Thunderstorms' that was held during the Academy's Annual Session in Delhi in December 1951. The so-called "nor'westers", the thunderstorms that lash the coastal Bengal area, was one of the interesting topics discussed. Raman took a lively interest in the lectures and asked several penetrating questions to obtain a deeper understanding of the atmospheric physics behind thunderstorms.

In the Annual Sessions held in Waltair in December 1956, 'Jet Streams in Upper Air' was the subject of a talk given by Dr C. Ramaswamy, Raman's younger brother. I remember this talk very well and can still picture Ramaswamy on the dais. He always felt nervous giving a talk before Raman, although he was a fine speaker once he overcame his initial fright. Raman evinced a keen interest in the lecture and asked many questions. He absorbed the account given by Ramaswamy and, almost a decade later, wrote two scientific papers about the origin of jet streams and the general circulation of the atmosphere. Many of the concepts discussed by Raman were well known, but he brought them all together to offer a simple explanation of the mean westerly jet streams in the upper troposphere and the zonal winds.

What impresses the reader about these papers is his remarkable freshness and simplicity of approach. For instance, he starts with the simple concept of the rotating earth and ends with the most important results in modern meteorology, all in a seven-page paper. Raman wrote these papers on meteorology when he was 80 years of age! He chose 'Weather and Atmospheric Circulation' as his lecture topic for the Gandhi Memorial Lecture delivered on October 2, 1967; it was later published as an article titled 'Zonal Winds and Jet Streams in the Atmosphere' in the issue of *Current Science* dated November 20, 1967. It was also the theme of his presidential address at the Annual Session of the Indian Academy of Sciences held at Madras on December 19, 1967.

Raman had the unique capacity to examine a problem *de novo* in a fundamental way. He approached meteorology as a classical physicist and often made brilliant suggestions. His students filled the India Meteorology Department and several of them acquired international reputation as meteorologists. On the lighter side of meteorology and meteorologists, Raman used to remark, "Meteorology has something common with astrology, for I cannot find a meteorologist who can predict the weather correctly". This used to evoke loud laughter from the audience, to the chagrin of some of the meteorologists present in the assembly. The person who was particularly

sensitive to such remarks was Raman's brother Ramaswamy, who used to defend the profession and the science whenever Raman was beyond the range of hearing. But seasoned meteorologists like K. R. Ramanathan and L. A. Ramdas enjoyed the joke with as much relish as Raman intended it to be.

Raman's deep interest in astronomy goes back to his early days. When he visited the California Institute of Technology, Pasadena, in 1924 as a visiting professor he had occasion to spend some time at the Mount Wilson Observatory, which was then at its peak. Apparently he spent a couple of nights in the mountains taking in the heavenly sights at night and exploring the surroundings during the day. The great 100-inch telescope had gone into operation and in the hands of Hubble had yielded some spectacular results, revising Man's concepts of distances in the universe. Raman too viewed the distant stars and gaseous nebulosities through this telescope and the experience stayed fresh in his memory, inspiring his vision of astronomy.

Raman used to often talk about the 200-inch telescope at Mount Palomar with wonder and amazement, saying what a technological marvel it was, scanning the sky with the precision of a Swiss watch. Mount Palomar dominated astronomical research for several decades and its telescope still remains the most powerful optical telescope in the world (see Raman's Convocation Address later in this chapter).

Raman had a strong desire to install a telescope in the dome of the Spectroscopy Laboratory at the Raman Research Institute, but he never got around to it. He had acquired a few large-diameter (one foot or so) reflecting mirrors from one of his friends, H. P. Waran (Parameswaran), and had dreamed of astronomy with them. He used to talk to Padmanabhan about making larger-diameter reflecting mirrors for a telescope and would ask if he could grind one of large--diameter. Padmanabhan the optimist would shake his head in the affirmative. Raman had a great appreciation of the science and technology of optics and believed that progress in astronomical science in a country depended on the existence in it of skilled opticians who

could grind, polish and figure great lenses and mirrors to the most exacting requirements.

Raman had filled the Raman Institute grounds with spectacular flowering trees, shrubs and lovely roses. All the best roses that the Bangalore nurseries could supply were planted in his rose garden under his supervision and he would admire them like a child with a new toy. He knew the botanical names of most of the trees and shrubs in the grounds of the Institute and had them planted carefully to maximise the effect of their floral display. He would go around his garden twice a day, to enjoy it, to relax in it and to think of Science. Many a time he would discuss physics with his research students while taking a stroll in the grounds. Almost every evening, weather permitting, he would go to Cubbon Park for a walk and on several occasions I accompanied him. It was a delight to walk with him, for he kept constantly talking about Science, Nature and other topics uppermost in his mind. He would look at the trees and admire their foliage and flowers.

Recalling an encounter with Raman in Cubbon Park, Ramakrishna, formerly a professor in IISc's Electrical Communications Department, says: "Dr Dhawan and I were walking in Cubbon Park and we saw Prof. Raman searching for something under a lamp post in the dusk. We asked him if we could be of any help and he told us to pick up some of the wings of the insects that come in thousands to a bright light on a suicidal mission, after a heavy shower in the summer months, and lose their wings. We did not have the courage to ask why he wanted them, but respectfully collected a matchbox-full of wings and took it to him. 'Now you can come with me', he told us and took us near a mercury vapour lamp on the roadside and held a wing against the light, and, lo and behold, the beautiful diffraction colours from the skeletal structure of the wings appeared in front. Only a naturalist like Raman can see how science permeates all life."

Sometimes he would pick up fallen seeds and admire their shapes, colours and polish. At times he would fill his pockets with them for a more thorough look at them in the Institute. Lady Raman would often find strange-looking seeds in his coat pockets and wonder about

them. When he reached a wide open space he would look at the stars and point out their names and character.

He would not miss the annual Horticultural Shows in the Lalbagh gardens, a lovely botanical garden near the south Kempegowda tower in Bangalore. Majestic trees of all sorts, rows of flowering trees, flower beds and a glass house are some of the features of this lovely garden. An admirer of Raman who happened to go to the flower show one year remembers: "The crowd had melted away. One lone figure was standing amidst the flowers with a magnifying glass in one hand and a beautiful Begonia in the other. He was studying the colour pattern through the glass. When I and some friends approached him, he looked at us. There was a far-away, dreamy look in his eyes which showed that his curious intellect had grappled with the colour scheme of the flower, which baffled him. Slowly he came back to earth and talked to us about the new research on which he was engaged."

Raman would run into everyone at the Institute at least once during the day to discuss work or exchange a few words. It was not the custom, however, for us to exchange any formal greetings. Many a time on his birthday we wanted to wish him, but none of us did so. Perhaps we felt that being insiders it was not proper for us to do so; perhaps it was the age difference which prevented us from communicating our sentiments. I forget the exact year. It must have been one year in the mid-Fifties when we all decided that we would wish him on his birthday. We got the Institute gardener to make a rose bouquet and I was chosen as the person to present the bouquet to Raman. I accepted the assignment on one condition, that the others would follow me. We all stood in the veranda in front of Raman's room and when he came out I promptly stuck the rose bouquet in his hand and all of us said, "We greet you on your birthday". Raman was taken aback for a moment by this act of ours, but was deeply moved. In those days he would not show any emotion outwardly. He took a sniff at the roses and said: "I say, these are lovely roses, where did you get them? I suppose they are not from my own garden?" We could not lie about the roses and admitted that they were

from the Institute garden. Then he said: "You should have left them on the plants. They would have looked more gorgeous there than in the bouquet. Anyhow, I thank you all." That was our first and last attempt to formally wish him.

Raman was fascinated by the Alps and the Alpine scenery. He had seen it from different points. Once he told me: "If ever you go to Europe, don't fail to go to Innsbruck and take a look at the mountains. This is one of the most spectacular sights." I did go to Innsbruck some ten years later and Raman's words rang in my ears when I saw the spectacular scenery before me. During his Calcutta days, Raman used to go to Darjeeling for vacations, and he would always afterwards talk about the sunrise, sunset and the majestic snow-covered peaks that could be seen from there. Mountains, lakes, forests, he loved them all and drank deeply of Nature whenever he had the opportunity. His absorption in Nature and Science could never be separated. He derived scientific inspiration from Nature and natural phenomena. He was a modern man in his scientific outlook, but was not distracted by mundane modernism.

For instance, he would never go to a movie for entertainment. Only once have I seen him going to a cinema house and that was to see a short documentary on the Raman Research Institute that the government Films Division had made. He took Padmanabhan and myself along with him to a movie house in South Parade in the Cantonment section of Bangalore to see this film. The manager of the movie house saw Raman coming and received us. Raman insisted that he would pay the admission charge and handed over ten rupees or so for three seats in the box section. The movie running on that day was *Anna and the King of Siam*. The documentaries are usually shown first in Indian cinema halls and we watched the short presentation on the Raman Research Institute in which Raman figured prominently. Raman was quite satisfied with the production and exchanged some comments with us. We then got up thinking that he would not like to sit and watch the movie. But he said: "I say, let us stay for awhile and see what this cinema is all about. After all, we

have paid for it." We sat for another ten minutes, watching Yul Brynner as the King of Siam. After a little while, Raman became restless and said: "Let us go. What is all this nonsense that they portray the King of Siam as a bald-headed savage. I don't like all this." We got up, left the cinema hall and drove home.

Clouds were another favourite lecture topic with Raman. Cloud patterns in the sky and the brilliant colours they displayed at sunset fascinated him. He was never tired of looking at the sky and sharing his excitement with anyone around. I once accompanied him and Lady Raman to the Air Force Officers Club in Jalahalli, a suburb of Bangalore, where Raman had been invited to give an after-dinner speech. He spoke about clouds! It was a fascinating lecture in which he explained how clouds form and how they assume various shapes. He spoke about cumulus and cumulo-nimbus, stratus and nimbo-stratus, and iridescent clouds. He explained how the beautiful diffraction haloes sometimes seen around the moon were caused by ice crystals at very high altitudes. The lecture was a thrilling experience and Raman was enthusiastically applauded for it. He was in great spirits that evening.

The Raman Research Institute museum possessed a collection of stuffed birds, beetles, shells of all kinds and other marine life. He had chosen these specimens mostly for their colour, or for the interesting structures they often exhibited. Among the birds were blue jays, golden orioles, pheasants. The beetles were either iridescent or exhibited some interesting pattern of colour. He derived tremendous pleasure looking at them periodically and talking to visitors about them.

He once bought from a taxidermist in Calcutta two beautiful stuffed Himalayan pheasants for the museum. We left these pheasants in an open almirah and forgot to lock the door of the room. As ill luck would have it, two mongrels got wind of the stuffed birds. They gained entry into the room at night and destroyed one of the pheasants beyond recognition. The next morning, when we came in and saw the spectacle, it was a shock. We knew that Professor would get very upset with us for not locking the room, so something had to

be done to cover up the catastrophe. We quickly ordered the servants to clean up the place and bury the remnants of the pheasants in a far off place.

When Raman came, he went straight to the museum room. Not finding one of the pheasants, he wanted to know what had happened to it. We had decided to maintain that there had been only one pheasant. Professor repeatedly said that he had definitely bought two and kept scratching his head wondering how one could have disappeared. Since we continued to maintain that there had been only one pheasant, he finally convinced himself that although he had paid for two, only one specimen had actually been sent to Bangalore. Then he went for a walk in the gardens, satisfied with his reasoning.

Twenty minutes or so later, he returned with a feather in his hand; it was obviously the feather of the same pheasant which the mongrels had torn to pieces. The man who had taken the remnants must have dropped a feather on the way. It was difficult to maintain our cover-up story, but we managed to convince Professor that some other bird must have dropped a feather on its flight. Raman must have wondered about it all, but did not ask any further questions. We felt very bad about having hidden the truth from him. But since we had just joined, we did not want to run the risk of being sent away by revealing what had actually happened.

The Raman spirit and his traits

Raman was an intense person who became engrossed in whatever subject interested him. Whether it was in the field of Science or outside it, he was never content with a superficial examination. When he was in the Financial Civil Service, he paid meticulous attention to his official duties and was lauded by his superiors for his prompt and intelligent way of handling anything connected with them.

There is a story, recalled by a citizen of Nagpur, whose collection of a few hundred-rupee notes was nearly burnt by a fire. The perturbed individual went to the Accountant-General's Office and presented the half-burnt bundle there, but with little hope of receiving any satisfaction. Any other officer would probably have shown him

the door, but Raman, who was then in the office of the Accountant-General, took the trouble to scrutinise the notes one by one, using a magnifying glass, and then instructed the treasurer to give the petitioner fresh notes. Raman argued that the numbers on the half-burnt notes were visible and it was, therefore, a genuine case. This incident is characteristic of the thoroughness with which Raman tackled all problems he faced. Between 1907 and 1917, the leadership Raman offered and the tremendous enthusiasm he whipped up for scientific research in Calcutta were reflected in his address at the Science Convention for 1917 held in the presence of Sir Asutosh Mookerjee. He said:

> "The ten years, from July 1907 to June 1917, which preceded my joining the University of Calcutta as Palit Professor of Physics, afforded me numerous opportunities for studying, as an impartial and disinterested observer, the efforts made during the period in this University towards fostering higher studies and research in physics. Looking back over these years, one cannot fail to be struck with the genuine progress that has been achieved and with the fact that, today, the Calcutta University can claim to possess a real School of Physics, the like of which certainly does not exist in any other Indian university, and which, even now, will not compare very unfavourably with those existing in European and American universities. What has impressed me most is the rapidity of the progress, the position now being very different from what it was ten years ago, and this is obviously a most hopeful sign for the future.
>
> My own work at Calcutta commenced in 1907 and was made possible by the special facilities put at my disposal by the present Honorary Secretary, Dr A. L. Sircar, who had the Laboratory kept open at very unusual hours in order that I might carry on research in the intervals of my duties as an officer of the Indian Finance Department. Gradually others were drawn in to take part in the revived activities of the Association. The success which has attended these efforts is indicated by the fact that during these ten years the Association has issued as its own publications, fourteen special *Bulletins*, and three volumes of

Proceedings, besides publishing its Annual Reports. These publications have been warmly received abroad, and the Association is now in exchange relations with about fifty learned societies and institutions in various parts of the world."

Raman went on to add:

"A wide range of subjects is at present attracting the attention of the Calcutta School of Physics. General Physics, Acoustics, Optics, Electromagnetic Theory, Electric discharge, Spectroscopy, X-Rays and Resonance Radiation and Radio-activity have all come in for a share of attention, and this wide range of interest will become even more manifest when our equipment is more complete, and I have had time to take on a large number of research workers and train them. .... Perhaps the most significant tributes to the fact that we have now a real scientific atmosphere at Calcutta are the numerous requests that have been received from teachers and scholars in various parts of India and Burma to be permitted to work in my laboratory and to carry on research."

In the closing section of his report, Raman stressed the need for (i) strengthening the equipment of the Department of Physics of the Calcutta University, (ii) provision of residential accommodation in the premises of the College of Science to enable the professors and staff to devote all their time to work in the laboratory, and (iii) enlargement of the careers open to workers. He concluded his remarkable address with the statement that "to most men, the knowledge of the degree of recognition that awaits successful work is a stimulus not to be despised".

His physical energy was as extraordinary as his mental output. An outstanding characteristic of Raman was that, unlike other persons, he seldom relaxed. He was always keyed up to fever pitch by the continuous thrill or excitement that the challenges and the ever-expanding avenues of scientific research provided his mind. He was capable of tremendous concentration on intellectual work, as the following incident will show. Once, in Calcutta, when he was in his

office at the Association, drafting a rather tough paper for publication, a Swamiji visited him. He welcomed him courteously, asked him to take a seat and said that as soon as he finished the work he was busy with, he would be glad to spend some time with the Swamiji. Then, for the next couple of hours, he was completely oblivious of the Swamiji. When he completed the task on hand, he suddenly looked up and found the Swamiji still waiting. Raman told him that as he had only five minutes now left before he had to attend another pressing engagement, would the Swamiji be brief. The Swamiji was equal to the occasion. He told Raman that deep concentration was what a spiritual person had to practise. And Raman already possessed this, as was demonstrated by the fact that he had been oblivious of all else for the past two hours while he worked. A donation the Swamiji then requested for a charitable cause was instantaneously given by Raman.

The period between 1920 and 1928 may be said to have been the golden period in the scientific life of Raman. Given the combined control of the Association and the University laboratories, he maintained a hectic schedule. L. A. Ramdas has described his activity at this time thus:

> "The daily activities at the laboratories of the 'Association' usually started by 7 a.m. Having started an experiment, one would go on working until 1 p.m. After a quick lunch, the scholars would be back by 2 p.m. and work on far into the evening and often until 9 or 10 p.m., until the job on hand had reached a satisfactory stage. Working at this furious rate, it is no wonder that many of the pupils could work through five or six major investigations each year. Those who could not cope with such a fast tempo of work would automatically drop off.
>
> By 1920, Prof. Raman had gathered round him an increasing number of extremely bright and capable pupils so that, more and more, he could get his research programme executed rapidly by them. He inspired his scholars to use their own initiative and ingenuity to the fullest extent. He would see what was going on and discuss results at intervals. At any given time, however, he would concentrate his atten-

tion on the particular scholar who was then entering the most critical phase of his research. Interpretation of results, fruitful suggestions to carry the investigation several stages further and quick discussion of results already obtained resulted in immediate publication from this effective type of collaboration between the Professor and the pupil. Each of his pupils had his opportunity for such exhilarating collaboration at the developing phase of his investigation. All the time, the pupils enjoyed the fullest freedom to think, work and improvise for themselves. Spoon-feeding of any kind was absolutely taboo. A spirit of perfect understanding and goodwill pervaded the entire 'Association', with Ashu Babu, the Assistant Secretary, ever ready to help us with any material or facility that we needed, the scholars themselves helping each other spontaneously."

Raman maintained this mode of working and dealing with students throughout his career. Anyone who wished to work under Professor Raman as a regular student had to undergo a searching oral examination in which the candidate's knowledge of fundamentals and capacity for original thinking would be severely tested. Although he attached importance to academic records, Raman always made a personal assessment. Once selected, the students felt at ease, for Raman was kind and large-hearted with them. Raman had his own way of developing self-confidence and self-reliance in students. He would treat them as his equals, while discussing scientific matters. It was his habit to go round the laboratory every morning, meeting each student and discussing the progress of his work, often suggesting new ideas. He would give free expression to his joy when a new result was brought to his notice. Nagendra Nath recalls: "One day, when I told him that I had found the explanation of the Raman line in diamond, which had been mentioned by him as an outstanding problem in his Nobel address, he asked me what it was. I said that the Raman line was to be attributed to the mutual vibration of the two face-centred lattices composing the diamond lattice. He simply yelled out, 'You are right, you are right', and insisted that the research paper should be immediately written up. He was in ecstasy over this work. I found

myself elected to the Fellowship of the Indian Academy of Sciences, at the age of 23, without an inkling being given to me by Professor."

To criticism that he was partial to students from Madras University, Raman answered, "They teach very little physics and hence I get very good raw material to work with". I don't think the criticism levelled against Raman was fair, for Raman's students came from all over India and he did not practise narrow parochialism. He chose them on the basis of merit and shaped them into scientists who went out to carry on the tradition of research wherever they went and worked in their subsequent career. Throughout his life, he had a very warm corner in his heart for his many pupils and they, in turn, knew they could always turn to him for any help that they needed.

In his public lectures, Raman would often refer to his students by name and talk about their work. All this was a thrilling experience to young students and a powerful incentive for hard work. A unique rapport was, thus, established between him and his students.

Thrill of quick publication

From the very beginning, Raman held the view that scientific results should find prompt publication. He practised this throughout his life. According to L. A. Ramdas, hardly a week passed in the Association at Calcutta without a detailed paper, and, often, shorter notes, being dispatched to foreign journals or to the Calcutta University Press, which published the *Proceedings of the Indian Association for the Cultivation of Science*. He was so very critical in composing and editing scientific papers, whether his own or of his pupils, that often it would get too late to post the paper to the publishers in the ordinary manner. So he would hail a taxi and rush to the General Post Office, pay the late fee and get the paper despatched in the nick of time. After many an adventure of this nature, he would share his joy, over sending away in time an important paper for publication, by treating the anxiously waiting group of pupils to a solid feast of *sandesh* and *rosogolla* that he would send for from famed 'Bhim Nag' of College Street, remembers Ramdas.

By securing such quick publication of the results of the researches carried out by himself and his scholars, Raman never allowed scientists elsewhere to anticipate his results. Invariably, a good scholar would have enough published papers to his credit so that, within a couple of years, and, occasionally, even within a year, he would be in a position to submit his doctoral thesis.

Raman encouraged his scholars to take up independent positions in scientific departments or in the universities quickly, for his policy was that his laboratory should be a 'source', not a 'sink' of young scientific talent. These brilliant pupils very soon carried the 'Raman tradition' of original research wherever they went and worked in their subsequent careers.

Raman as a teacher

I quote from L. A. Ramdas's article on Raman as a teacher:

> "Prof. Raman, as a Palit Professor, had no teaching responsibilities, but he enthusiastically took part in M.Sc. teaching. He held the view that when a leading research worker takes on some special teaching course, he brings to his teaching the freshness of research and the questioning attitude which makes all the difference between dull pedagogy and inspired teaching. To some of us who had joined the M.Sc. course at Calcutta (both myself and the late Dr K. S. Krishnan had joined the M.Sc. course in physics at Calcutta by 1920) Prof. Raman once made the side remark that the best way for him to master or revise any subject in physics was indeed to lecture on it to the M.Sc. classes.
>
> The M.Sc. teaching used to be naturally shared by the various professors and lecturers. Prof. Raman took "Electricity and Magnetism" in the year 1920-21 and "Physical Optics" in 1921-22. Both sets of M.Sc. students felt that they were indeed listening to a type of inspired teaching to which was brought all the original flavour and excitement of the great giants of the past who had built up the subject under treatment. In listening spell-bound to Prof. Raman's lectures in "Electricity and Magnetism", covering a series of nearly 30 lectures,

we had shared with him much of the excitement and superb thrill that Benjamin Franklin, Oersted, Arago, Gauss, Faraday, Maxwell, Hertz, Lord Kelvin and many others must have felt while they were making their actual discoveries. This was indeed no routine text-book learning, but reliving the actual past history of the subject.

Almost regularly, Prof. Raman, with his genius for the subject, his extraordinary eloquence, imagery and fullness of precise expression, used to forget himself as well as the time and used to lecture for far more than the prescribed one hour, while the next lecturer was politely (and perhaps with a sense of relief) retiring from the scene after seeing Prof. Raman still at his lecture! Often he used to take the entire forenoon, for more than two and sometimes even three hours — such was his tremendous love of teaching. The mathematics was worked through often with his own improvised simplifications and fully illustrated with physical analogies. Any question or point raised by a student would start him off towards uncharted grounds, not touched upon in any textbook. His ready wit and sparkling intellect were a treat to the classes. And after each lecture we used spontaneously to look up original papers and classical treatises like Maxwell's "Electricity and Magnetism", J. J. Thomson's "Conduction of Electricity", Faraday's "Experimental Researches", Lord Rayleigh's and Kelvin's "Collected Papers" and so forth. The lecture in which he worked out Maxwell's field equations and showed that light waves are only electromagnetic waves and the thrill he communicated to the class are still fresh memories.

In "Physical Optics", a topic on which he himself was conducting several investigations at the time, the students were introduced to all the topics coming, as it were, hot from the 'Lab', and the lecturer's flair for dipping straight into the great masters like Huygens, Fresnel, Mascart, Schuster, Wood, Rayleigh, and others of the late 19th and the early 20th centuries, imbued the students with a real love and enthusiasm for what they learned at Prof. Raman's feet, as it were. Whether the subject was "Thermodynamics," or the "Kinetic Theory of Gases" or "Modern Physics", Prof. Raman's treatment of the topic

at hand was original and inspiring and left a permanent impression in the student's mind.

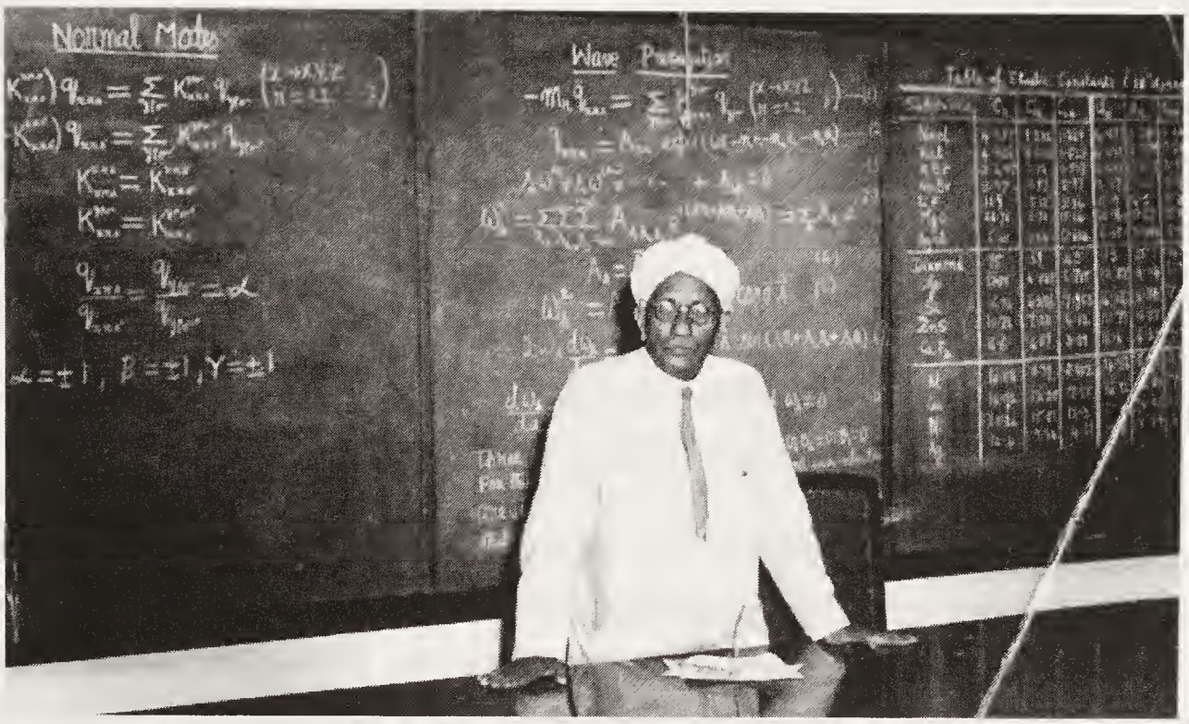
"Now let me record a few reminiscences. As an M.Sc. student having direct and free access to Prof. Raman's own personal library, I was astounded to discover that in each and every text book which he had learned from in his own student's career, there were marginal criticisms or appreciations of the author. There was no book in which every example and question had not been worked out by Raman. Some questions had the side remark "excellent", while not a few were apostrophised as "elementary" or "silly"! I had no doubt that Prof. Raman had been a most painstaking student and that the definition of 'genius' as the 'capacity to take infinite pains' is indeed true."

Raman thus fully participated in teaching and inspired his students with his enthusiastic lectures. M. N. Saha, who later became famous for the 'Ionisation equation' named after him, and S. N. Bose, discoverer of 'Bose statistics', were some of the other lecturers at the University College in 1917.

Raman lectures

Raman excelled in public speaking and could give a lecture on, for instance, Egyptian History, off the cuff. His scientific lectures were a treat, for he was a superb entertainer. They were delivered in a high-pitched resonant voice which reached the entire audience, making loudspeakers unnecessary. Rich in imagery and eloquence, and replete with spontaneous jokes, the lectures were given in so popular a style that every listener felt that he understood all the science that the learned lecturer was discussing. Once, he told me that "the hallmark of a good speaker is that the audience must be under the delusion that they have understood everything that was said by the speaker". And that is what he used to do, whenever he gave a public lecture — he would create in the minds of thousands of his listeners the illusion that they understood everything he spoke about.

Raman's typical way of giving a lecture has been beautifully described by Kashyap:



Raman as a teacher
(Photo Courtesy : Raman Research Institute)

"A tall, turbaned figure, casting those searching and curious eyes almost with child-like fitfulness, would walk directly to the dais, with an occasional turn to the right or left, acknowledging a remark or answering a query by the sponsors of the lecture who were leading him to the dais. Confidence incarnate was the figure and even before he started speaking one got the impression that here was a lecturer who would deliver the goods.

His very presence perhaps cut short the long-winded preambles and welcomes that often mar the beautiful effect of a nice lecture. Prof. Raman meant business and a disapproving look would stop a vagrant introduction. His first words uttered in a characteristically punching manner would set the pace for the lecture.

He spoke of soap bubbles. And, mind you, for some half an hour the evanescent soap bubble that hardly lasts for a couple of seconds blissfully lived!

Raman asked 'Have you ever thought of keeping the soap bubble alive for a long time?' An intriguing question — a question that had never occurred to many. The problem you know, Raman went on to say, is to see that the droplet of water does not collect at the bottom. Then he went on to say how he and other scientists, some in France, managed

to keep a soap bubble alive for a few days by subjecting the bubble to an oppositely directed force.

One would never have a dull moment and would not even realise that the lecture was over. To listen to Raman was something more than learning physics. He had the knack of using the most appropriate expressions, which no textbooks could give. He had the habit of tugging the lapels of his coat which was a Raman characteristic. He would invite questions and answer them all with astounding clarity."

He was forthright when he criticised. During the annual meeting of the Indian Academy of Sciences in Baroda in 1958, he interrupted the talk of a high-energy physicist who was filling the blackboard with mathematical equations, and said: "My dear fellow, please try to explain what you have done in a few sentences. If you cannot do this, it is not worth knowing."

At the annual meeting of the Academy held at Osmania University, Hyderabad, in the mid-Sixties the then Governor, who was also the Chancellor of the Osmania University, gave a long welcome speech. During the course of the speech, the Governor stressed the importance of scientists stopping 'ivory tower' research and diverting their attention to problems connected with import substitution, export promotion and defence preparedness. After further advice along these lines to the Fellows of the Academy, the Governor concluded: "Now, you will hear the learned address of Prof. Raman who is going to speak on the 'Physiology of Vision'. You and I will not be able to understand what the learned lecturer is going to say, but as you all know, Prof. Raman is a Nobel Laureate and a great scientist."

Prof. Raman, well known for the clarity of his speech and simplicity of his scientific message to a general audience, was obviously hurt by the Governor's 'Welcome Remarks'. He, however, did not reveal his feelings but went on to deliver a remarkably lucid and clear enunciation of his findings during the year on the 'Physiology of Vision'. Then, before sitting down at the end of the lecture, he turned to the Governor and said: "Mr Governor, when I received the Nobel Prize, my illiterate old aunt asked me to explain what exactly

I had done to merit such a prize. When I explained to her the finding referred to as the 'Raman Effect', she remarked that what I had discovered was so simple that she was surprised that my findings should have merited such a high international prize. I hope, you, Mr Governor, were able to understand at least some of the things I said." He then sat down amidst a prolonged, standing ovation.

Raman's lectures were painstakingly prepared and illustrated with colourful slides and diagrams. I often used to prepare these for him and he would ask me to operate the projector, for he could not stand an erring projectionist. I once photographed in colour optical effects exhibited by several gem materials. Colour photography was still an art in those days and not mechanised and automated as at present. Raman took the film with him to Bombay and had it processed. The colour slides turned out to be very good and he was therefore tremendously happy. He immediately sent an express telegram to me in Bangalore conveying how pleased he was with the outcome. Not only would he always express spontaneously his appreciation and admiration for any good work, but he would also acknowledge in public how so-and-so had done a marvellous job, had discovered something nice, or had a good idea.

The excellently lit Raman Institute hall was very well equipped. It had a fine black ground-glass board covering almost the entire wall on one side. A long, finely polished teakwood table was positioned in front of the speaker. One hundred plush, cushioned chairs made of teak and upholstered in black velvet were arranged neatly in rows, on an ascending platform. The chairs, wide and with arm-rests were very comfortable. Raman wanted the most comfortable seating possible for the audience in his lecture hall. He used to deliver all his scientific lectures as well as special lectures here.

Every year, in October, he would give what was called the Gandhi Memorial Lecture. The Gandhi Peace Foundation had created a special endowment fund for this lecture. These lectures were well attended, for it was one occasion when the public could listen to Raman. The lectures were free, but tickets were issued on a first-

come, first-served basis. Raman used to take a scientific topic on which he was working or he would choose one that he had some interest in and make a masterly presentation of it. On one occasion, he spoke about the 'Physiology of Vision', on other occasions he talked about 'Earthquakes', 'The Atmosphere', 'Voice' and 'Speech and Language'. The last Gandhi Memorial Lecture he gave was on October 2, 1970.

Some reflections on Raman's personality

There are some features of Raman's personality that have been noticed and admired by those who were close to him as well as by those who knew him only at a distance. He was richly endowed with a child-like sense of wonder at the unknown and un-understood facets of Nature and, throughout his life, he was pushed into exploring these aspects. Such being the motivation, he was often, and appropriately, referred to as a Child of Nature; nothing fascinated him more than Nature itself. Subjects like the origin of colours in minerals, birds and butterflies, the blue of the ocean, the sky, and other natural phenomena were his primary concern. On the other hand, he could never reconcile himself to the fact that large human resources and material wealth were being put into such programmes as those that dealt with Space and so on, which did not concern themselves with things on earth with anything of immediate interest to mankind.

His delicate sense of humour, his ability for biting sarcasm when needed and, above all, his love of Nature became very evident whenever Professor Raman wrote or spoke about any subject. On one occasion, while speaking about the countryside and weather, he prefaced his talk with the following remarks:

> "To the dweller in the towns, the weather is nothing more than a minor inconvenience which can be minimised by a little forethought in the matter of taking an umbrella instead of a walking stick when going out of the house. I will go so far as to say that the average city dweller is scarely conscious of the weather except when he is reminded of it in some particularly unpleasant fashion. The changing panorama of the skies, the most gorgeous sunrises and sunsets, pass mostly unheeded

by him, for, alas, the only landscapes that stretch before his eyes are long rows of tenement houses, and, as for the sky, it is only seen in little patches here and there, not infrequently cut across by great bunches of telephone wires. The only stars that he sees at night are those that shine on the silver screen at the cinema theatre, and as for the sun and the moon, he knows they are there but does not feel called upon to take notice of them more than he can help."

His own attitudes to certain basic issues of Science and its progress were often expressed in his public speeches and private conversations. Here is an example of what he thought about discoveries in science:

"It should be mentioned that the reception given at first to even capital discoveries by the outer world is not always one of respectful admiration for the achievement of the discoveries. One of the commonest ways in which the achievement is sought to be minimised by the unthinking or the envious is by attributing it to accident or a stroke of luck akin to the winning of a lottery ticket. Such comments are, of course, deplorable and indeed quite meaningless. The idea that a scientific discovery can be made by accident is ruled out by the fact that the accident, if it is one, never occurs except to the right man. The happy discoverer in Science is invariably a seeker after knowledge and truth, working in a chosen field of his own and inspired in his labours by the hope of finding at least a little grain of something new. The commentators who like to consider discoveries as accidents forget that the most important part of a scientific discovery is the recognition of its true nature by the observer, and this is scarcely possible if he does not possess the requisite capacity or knowledge of the subject. Rarely indeed are any scientific discoveries made except as the result of a carefully thought-out programme of work. They come, if they do come, as the reward of months or years of systematic study and research in a particular branch of knowledge."

One of his favourite comments was about Science being a very particular and difficult mistress. He would say that she would not

yield if you wooed her for her wealth; she insisted that you love her for herself and, even then, she would never give herself up completely to anyone but would reveal her secrets only in part and only little by little. As many discerning critics have said, let us not forget, when we discuss and attempt to assess Raman, that he is the greatest contribution India has made for many centuries to systematised human knowledge. We should not fall into the trap of regarding him as *just* a successful scientist, like we generally regard other successful scientists or successful businessmen or successful politicians. Men like him are not thrown up every day and, if the rugged contours and the sharp corners of this giant did not compromise with the soft-spoken ways of the successful world, we can only describe the phenomenon by stating that "it is no reproach on Everest that one cannot play golf on it".

That Raman had to work amidst disappointments, had to struggle and survive many difficult situations before reaching the pinnacle of scientific glory the hard way is not often clear to many. He occasionally used to slip into a reminiscent mood and say that the more he looked back on his career, the more he felt that it had been a long history of frustration, disappointment, struggle and every kind of tribulation. It sounded incredible but true, although some comfort and self-confidence were forthcoming in the same breath, when he used to say: "There have been a few gleams of success. It was poverty and the poor laboratories that gave me the determination to do the very best that I could". On one occasion, after reading a glossy biographical note written by one of his associates, Raman remarked that the biography tempted him to picture himself as a prince sitting in a gold chair marching from triumph to triumph, without a tear. While he wished that the picture were true, he knew that in fact it was not so.

In the life of great scientists, there have invariably been periods of distress amidst the joys of scientific successes. Raman's life was no exception. He had to face difficult times both in Calcutta and at the Indian Institute of Science, Bangalore, causing him severe emo-

tional drain. The difficulties had nothing to do with Science but with the politics of Science of the times.

After the discovery of the Raman Effect in 1928, and following the award of the Nobel Prize in 1930, Raman became a celebrity, his stature in India and abroad growing to new heights. Raman's rise to scientific eminence, power and prestige caused envy in some quarters and Raman had a trying period. The last few years of his stay in Calcutta were by no means happy. Some individuals accused him of not having been fair to young students from Bengal and attributed motives to the manner in which he selected his colleagues and his assistants. Although much of this was a parallel growth alongside his increasing reputation and growing scientific eminence, and was ignored as such by many discerning persons, it nevertheless assumed ugly proportions occasionally. His connections with the Indian Association for the Cultivation of Science, where undoubtedly his best scientific work was done, had to be broken off in an unceremonious manner. He had to defend himself by sharply reacting to public criticism. At one stage, he made a statement that he could have contented himself "by creating only a Bengali School of physics and not an all India school. But, in that case, I am quite certain that the Nobel Prize in physics would not have come east of Suez".

One of the leading daily newspapers of Calcutta wrote, in an editorial critical of Raman's methods, that "a scientist is not, however, necessarily a good administrator, and eminence in science is not always a substitute for many of the ordinary virtues which count as much in public as in private life". On the other hand, it must be said to the credit of Calcutta that there were many broadminded persons with sufficient vision who described him as an uncommon genius whose methods and outlook on things had to be accepted with respect, even if they were not similar to those adopted by a common administrator.

Again, at the Indian Institute of Science, he had to face a trying period connected with the position of Director, to which he was appointed in 1933. The problem this time was that the policy-making body of the Indian Institute of Science did not like the way in which

Raman ran the Institute. Everything he tried to do was considered wrong and he had to resign from the Directorship in an atmosphere charged with tension. But he retained his Professorship and continued his scientific research until his retirement from the Institute in 1948.

All this makes one wonder if Raman's genius would have been better utilised if he had been given the chance to continue his interests in a less bureaucratic setup. It is by a miracle that he walked into such a setup in 1907 when he chanced upon the Indian Association for the Cultivation of Science, and later in 1917, had offered him, by a far-sighted Vice-Chancellor, Sir Asutosh Mookerjee, the Palit chair of Physics at the Calcutta University. But for this, Raman would have retired as a "faultless Accountant General", as C. Rajagopalachari once put it. It was a stroke of immense luck for India and Indian Science that the accidental meeting of Raman and the Indian Association came about. The course of life is often shaped by accidental happenings and it is perhaps meaningless to speculate on what would have happened under some other imaginary conditions. Under British rule, opportunities for research in India were rare and it was very fortuitous that Raman came across the rare one, fulfilling the mission of great scientific achievement to which he was born. Raman was a rare phenomenon in India, indeed in the world.

Raman was quite a relaxed scientist at his own Institute. The bitter lessons he had learned in Calcutta and at the IISc, in Bangalore made him very sensitive to criticism and scared him off bureaucratic organisations. He, therefore, founded the Raman Institute with private donations. When he went to collect money from the industrial houses of India, someone made the remark that the greatest scientist of India should not go begging for money. He replied, "Our greatest men were beggars; take Buddha, Shankara or even Gandhi".

It was Raman's great desire to put the Institute on a firm financial foundation and make it one hundred per cent independent from government or any other controlling interest. He strived very hard all through his life to achieve this.

Raman heard from knowledgeable sources that in the state of Andhra Pradesh, near the sites of the old Vijayanagar empire's citadels, there were great treasures of gold and coins buried in the earth. Raman dreamed of unearthing some of these treasures to establish a sound financial base for the Institute. He talked to me one day about treasure hunting and suggested that I should look into electronic devices that could be used for detecting treasures buried underground. I read some books and constructed a powerful device with an appropriate probe. The device was basically an electronic oscillator whose frequency would undergo a sizable change, due to a change in its inductance, when the probe was placed in the vicinity of a metallic object. We were to carry this oscillator in a vehicle and search for hidden treasures over a designated area in Andhra Pradesh. For some reason or the other, the actual operation did not take place. Perhaps Raman realised that it was a foolish idea.

After Nehru's visit to the Institute, Raman felt that it was pointless to approach Government for endowment money and he decided to approach the Ford Foundation for funds. He prepared a document detailing the Institute's assets, the ongoing programmes and his plans for the future. This document was richly illustrated. In fact, he asked me to take a number of photographs of the Institute and of his estate in Kengeri village, which he intended to gift to the Institute. It was Raman's idea to turn his country home and the estate into the nucleus of an astronomical and astrophysical research centre. We went on a special trip to Kengeri and took several photographs of the estate. The whole write-up was quite tastefully done and Raman beautifully argued his case for funds. The Ford Foundation, however, did not respond positively and Raman was very disappointed.

The Ford Foundation had funded many projects in India, but they were mostly in the field of agricultural improvement or sociological studies and had to do with country's development projects. Very few private institutions got funding from them. Being an American organisation, and that too a Foundation representing the name of Ford, Raman thought they would be more responsive to his request.

Raman's personal wealth grew to a respectable size over the years. He mainly invested in real estate, and his properties alone were worth several million rupees. He had also direct interest in two chemical industries. He bequeathed all his personal wealth to the Institute.

Among the chemical enterprises in which he had interest was a small company known as Bangalore Chemicals. The main product of this company was the manufacture of mantles for Petromax lights. Raman encouraged Dr P. Krishnamurti a former student of his, to start this venture, providing the seed capital. Krishnamurti was the chemist responsible for the operation and the manufacturing of the product. The total investment must have been Rs 400,000 or 500,000, of which Raman's share was about a fourth. The product was excellent and sold extremely well. The return on capital was substantial and Raman used to get something like Rs 150,000 annually as his share for over a decade. Raman gifted these earnings to the Institute and held the shares in trust. A good part of the Institute's budget came from this source. He also used this money to put up additional buildings.

Raman also invested a sizeable amount in another venture called Travancore Chemicals, for which Krishnamurti was again instrumental, being the technical power behind it. The company made fertilisers, pesticides and other chemicals. Raman used to have the Board meetings of this company at the Institute and took a keen interest in the technical as well as the commercial aspects of the company.

Personal views and ways

There have been questions often raised about Raman's belief in religion. During the eleven years of my association with him I gathered the impression that he was not a religious person, but I also never heard him proclaim that he was an atheist. On two occasions I saw him offer worship, in the famous temples of Tirupati and Chidambaram, when the annual meetings of the Indian Academy of Sciences were held in those temple towns, in 1957 and 1959 respectively. Accompanied by many Fellows of the Academy, Raman took part in the worship at these temples, stripped to the waist and wearing

the *dhoti* in the *Panchakacham* style. On both occasions, Bhagavantam was also present.

Raman was a self-made man with an indomitable will and total absorption in Science. His dedication to Science, which he practised during his entire lifetime, was so intense and in tune with the traditions of Indian scholarship that it would be justified in describing him as a real *Rishi*. Nature was his object of worship. The mysteries of the Universe constituted the goals of his meditation. There were very few occasions when divinity and God-head meant anything very different to him, from all that is manifest to Man in the wonderful world around him. He would not generally let himself be drawn into conversation about God, but if anyone tried to do so, his reluctant reaction was that while there was so much to learn about Man, in fact much more than what one could chew, why worry about God. In his public utterances, he seldom spoke on religious matters. He did, however, say, on one occasion, something about what he called his own interpretation of Gautama Buddha and Ramakrishna Paramahamsa. This drew critical comments from some who claimed to be experts on such matters. One of the few instances in his writings where a reference to divinity is made, is a letter in his own handwriting reproduced in one of the memorial articles written after his death. It reads, in part: "It is my earnest desire to bring into existence a centre of scientific research worthy of our ancient country where the keenest intellects of our land can probe into the mysteries of the Universe and by so doing help us to appreciate the transcendent power that guides its activities. This aim can only be achieved if, by His Divine Grace, all lovers of our country see their way to help the cause."

Raman had a small tuft beneath his turban and used to wear his sacred thread. I do not think these external forms of orthodox Hinduism really meant anything to him, but it is interesting that he did not cast away these symbols. He was certainly not an orthodox Hindu Brahmin, but he held some conservative views. I give an instance from personal knowledge. He heard that a young Indian scientist known to him was going to marry a Westerner and was quite

upset by the news. He asked me if he should advise the young man against it. I, however, told him that it was too late for such advice, and, in any case, it would not reverse the decision. He was quiet for some time and then said, "It is his look-out; why should I worry about it?".

Raman was a teetotaller and a strict vegetarian. He preferred simple food, often bread, banana, milk, curd and rice. Commenting on the deliciousness of rice and curd, he has said, "For the South Indian there is nothing sweeter than this". On another occasion he extolled the virtues of *rasam* and the South Indian partiality for this dish. At the annual meeting of the Academy held in Sri Venkateswara University, Tirupati, there was an excellent lecture by Dr Padmanabhan on 'The Present Status of the Rice Diseases and Their Control in India'. After hearing this lecture and enjoying the delicious South Indian meals served during the conference, Raman went into an ecstatic praise of the talk by Padmanabhan. Then he thundered, "It is *rasam*, you know, it is the *rasam*". Raman must have meant that *rasam* generates good thinking!

Once, after a lecture, a well-known German professor, who was with the Aeronautical Engineering Department at the Indian Institute of Science, asked him, "Raman, how do you get such brilliant ideas?". Raman replied: "My dear Sir, that is a secret of mine, but I will tell you. I get up very early in the morning and have a cup of Brahmin-made coffee prepared by my wife to stimulate the brain."

On another occasion, he was coughing badly and I suggested that Waterbury's compound would do him a lot of good. He said, "Let us go and get it". We drove to a nearby pharmacy and I bought a bottle of Waterbury's compound for him. In the car, he began reading the label. He suddenly stopped at the line *'15 per cent alcohol by volume'* and said: "I say, this thing contains alcohol. I can't take this medicine. You can use it, when you suffer from cough next time." In spite of my entreaties, that it was only a medicine, he refused to take it and I ended up with a bottle of Waterbury's compound.

In this context, there is an incident which took place in Bordeaux at a banquet in 1948. Raman was the chief guest and a toast was pro-

posed in honour of his visit. Prof. Cabannes, a famous French physicist, proposed the toast and everyone present held a glass of sparkling wine in their hands. Raman, however, picked up a sparkling glass of water and said amidst laughter, "Sir, I know what my effect on alcohol is, but I certainly don't want to try the effect of alcohol on me". So saying, he drank the glass of water to the toast. Recalling this incident, Raman seems to have remarked to Dr Balakrishnan, a nephew of his, that "there was only one person who was not under the effect of wine, and that was a lone South Indian Brahmin".

Raman had a tremendous aversion to smoking. His dislike was so intense that any of his students caught in the act had to face dire consequences. Dr P. Nilakantan, a favourite student of Raman at the Indian Institute of Science, told me this. Another smoking story relates to Prof. Mahadevan, a well-known geologist who worked under Raman. Narrating what happened during an Indian Academy of Sciences annual meeting in Pune in December 1944, Dr Lakhanpal says: "Quite a few delegates were going in an open vehicle from our place of residence to the venue of a lecture. A car approached from behind and passed us by. Amongst its occupants was Prof. Raman. As soon as Prof. Mahadevan, who was sitting with us and enjoying a cigarette, saw the turbaned face of Prof. Raman, he ducked his head, like an erring child, to avoid being seen by the great scientist."

It must have been January 1952 when the Indian Science Congress was held in Bangalore. There were several foreign invitees and one of them was Prof. G. Wentzel of the University of Chicago. He was a cigar smoker and preferred a cigar of the most pungent variety. He came to visit the Raman Institute and Raman took him around. Wentzel started his cigar somewhere half way. It was agony for Raman, but he did not say anything. After Wentzel left, he said that he would have to put up a 'No Smoking' sign and would not admit anyone into the museum who smoked.

Raman always told people what he felt and in the process hurt many. The controversies in Science in which he got involved, particularly those related to lattice dynamics, also made him a bitter person. When it came to any kind of discussion of this subject, he

always insisted he was right and the rest of the world was wrong. Aside from these sensitive spots, he was a charming person. His greatest gift was the ability to turn his mind to Nature and revel in it.

Raman's deep feelings for Nature, his views on education, Science, Science policy, technical progress and the need for self-reliance, are best reflected in the Convocation Address delivered by him at the Indian Institute of Technology, Madras, on July 30, 1966. This address, so typical of Raman, attests to his seriousness and fearlessness, clarity and honesty, and should be assimilated by every thinking person. I reproduce it below with the permission of the Director of the IIT, Madras.

The IIT Convocation Address

Nature and human life

> "I have, in my fairly long life, been at many Convocations, at some of which I received a degree of some sort or the other. I have never seen such an assembly or gathering that so impressed me as this one, which I have been privileged, with your kindness, to address.
>
> Just before I came to the Convocation, the Director was taking me on a 'joy ride' through your campus. I think I should correctly describe this as a joy ride. It was just thrilling, thrilling to see the wonderful old banyan trees or the wild grasses, the thorns here and there and occasionally a 'few' buildings by the way! Well, that is as it ought to be. Because I always thought that study, examinations, books, lectures and so on are but a very little part of a man's or a woman's, I should add woman's also as I should not forget them, education.
>
> I have always said to myself and others that I regard as the greatest feature of the world Nature herself. She is the supreme artist; she creates forms of beauty, loveliness and colour, unsurpassable, and this has been so from the beginning of time. She is the inspiration not only of artists, painters, sculptors and engineers, but also of men of Science. When I say this, I remember, many years ago, I was standing below the pillars of the temple of Luxor. What did I find at the top?

Raman presenting a diploma to a student at IIT Convocation.

The lotus, papyrus. These forms of beauty of Nature have been the inspiration of all mankind. Well, I should say that they should also be the inspiration of all these graduates of the year.

Usually, technology and industry are associated, I don't say justly, with squalor, dust, ugliness, smoke and all sorts of abomination. That ought not to be so. I think your education is imperfect if you do not realise, my young friends, that life is not merely a question of getting food, clothes and shelter. Man does not live by bread alone. This has been realised from ancient times. I think that the finest things in life are not these, but music, colour, flowers, beauty, aesthetic sense, the satisfaction derived from those. We in Madras do not have to lament about music, I think. You are all music-minded. If you are not, I feel sympathy for you. It is those finer things in life that make life worth living.

You, by the great kindness of no less than three mighty powers, the Central Government of India, the local Government of Madras, to say nothing of that mighty German Republic, have been privileged to live in this wonderful area, with these magnificent hostels, with these great

laboratories and, above all, in the midst of these lovely trees and open air. You at least will not die of tuberculosis. I was privileged to be shaken by the hand by some of your prize men. I considered it a privilege to shake hands with them. If I did it with all the graduates, my hands will not be fit to hold anything. They were hefty young fellows with plenty of grip in them. That is as it ought to be. What use are you engineers if you cannot lift up a hammer? Physical strength, energy are the basis of engineering. So, I find, you have been taken care of well.

The German gift

It is only right and proper that I should make some reference to the great country, Germany, which has helped in no small measure to make it possible for you to receive the education that you have had during these years. To me, when Germany is mentioned, I do not think of Germany on the map. Germany brings to my mind the great masterminds which made Germany what she was. I can mention a score of names. I just mention two who have been recognised as among the greatest of philosophers and men of science the world has ever seen. Hermann Von Helmholtz in the 19th century and Albert Einstein in the present. I could recite a score of names. Every one of these has written his name in an imperishable way in the records of Science. These, and not the country Germany, nor all that happened to Germany, recall Germany to my mind. It was for many years my earnest desire to go round and spend a few weeks in Germany, visit these ancient centres of learning, small though they may be in geographical extent but great in the lustre of their names. Heidelberg, Göttingen, Marburg and so on. I will never be fortunate enough to spare that time or get that opportunity.

But ten years ago, I received an invitation to attend a conference at Lindau and I thought here was the opportunity for me. I went there, and Lindau is a curious place. How curious it was, I will not mention. It is a place on the edge of the lake we call Lake Constance, the Germans call it Bodensee, whether it is the correct pronunciation, I don't

know. Lovely little place and it was a free city of the Empire. And one of the freedoms it possessed was to be allowed to run a casino, or a gambling place. You know it is not a very nice kind of freedom. They ran it and made and still make money. People think that when you go to a gambling den you are going to make money. Nothing of the sort. It is the man who keeps the gambling den who makes the money. Lindau made a substantial profit every year and the conscience of the councillors bothered them a little at having this ill-gotten wealth. So what they did was to compromise with conscience. Every year they have a Conference to which they invite nobody other than a Nobel Prize man. A Nobel Prize is the minimum qualification to be invited to this Conference. Year after year, they hold it in succession. Ten years ago, I was invited to this Conference. I went there, I was not sorry I went there, because it is a lovely place. The most beautiful place, right in the middle of the lake, is an island called the island of Mainau. Mainau is owned by Count Bernadotte. He comes from the Swedish Royal family. He was the host of this function.

Afterwards I moved on to that old university, one of the very first universities which gave an honorary degree, the ancient University of Freiburg in Breisgau. I was there for a week and then I moved on to Bonn. And then from Bonn to Munich before I came out of Germany. I am mentioning this because I was in Bonn for just a week. I had a wonderful time. You know, at that time, Germany had, even in 1956, not recovered from the devastations of the War. They were working very hard to clean up the devastation. I was enormously impressed by the Museum of Mineralogy which had been set up in Bonn. It is absolutely incredible how from a devastated country they could get together such amazing beautiful collections of rare and beautiful specimens. That is one of my happy experiences. Others I will not mention.

And on that occasion, it so happened — all this is introductory to my remarks that when I was there, our late Prime Minister, Jawaharlal Nehru, was also there. I want you to realise that he was not there because I was there. Nor was I there because he was there. A

pure accidental coincidence. Such coincidences always happen, as you know. I think the Indian Ambassador there thought that this opportunity should not be missed. So I was invited to a lunch in the President's house at which the President of the German Republic, Mr. Nehru, the Indian Ambassador and a few others sat round the table. One of the curious things that happened at that meeting was the President made a speech in German which lasted about 5 to 10 minutes. And then, at the end of it, the interpreter got up and translated word for word the whole of the 10-minute speech in English. Then Mr. Nehru got up and made a speech in English. The interpreter got up and translated the whole speech word for word into German. But I must confess that I do not remember at this distance of time what exactly they spoke. But I presume it was the usual declarations of mutual love and affection which are always made when great dignitaries meet. Why I am mentioning this is because, it was on that occasion, I read from your book, that the German Republic promised to give a gift of this Institute.

Well, just ten years ago, imagine ten years ago. I find it very difficult to understand how in the course of ten years a veritable jungle full of, presumably, snakes and cobras has been transformed into this beautiful place of learning and how so many buildings and so much equipment and so many bright young people from all over India have gathered together and such a magnificent assembly presented for my delectation. I enjoy this, particularly because I love colour. As I have mentioned on many occasions, there is an unwritten law that men should not wear bright colours as a rule. Women are allowed to wear colours as you know and they always do. But there are exceptions. And a convocation is one of these exceptions when the men are allowed to flaunt all the bright colours in the spectrum and a few outside the spectrum as well, for the delectation and admiration of those round them and specially members of the feminine sex who will be around.

Youth and freshness of outlook

Well, as I say, it is a very enjoyable occasion and I think my young friends are all extremely happy to have had this great occasion. It must stand out in their memory for a long time to come as the unique occasion in their life. Well, I remember myself, you see my mind goes back to a period sixty years ago, fully sixty years ago, I also came out of a college which is in the same town, with a degree in my pocket and a few other things, I won't mention what. Now that occasion stands out for one reason and I want to mention that reason. Looking back over the years, I find to my astonishment, to my surprise, that the experiences which I went through in those four years have left an indelible impression on my mind, an impression that sixty years of time and all that has happened since has not succeeded in dimming in the least. What is even more remarkable is this — it is perfectly true to say that what I am today, what I have done in the last sixty years, has all been determined for me with absolute mathematical precision by what I did in those four years. The opportunities that I had during those years, made me turn my mind to certain things. I have found it impossible to turn away from these, because of the force in me of those youthful days. I was only 14 years of age when I entered the Presidency College and 18 when I came out with my Master's degree and an appointment as an Officer of the Finance Department, and a published paper as a budding scientist. All these at the age of 18! At that early age, the mind is so impressionable. And what I did then had determined my whole career.

I want to stress this because I want you, my young friends, to realise that in these years, three or four or five years as the case may be, you have been subjected to the influence of a band of teachers, you have been subjected to the influence of the old banyan trees around, which I don't regard as unimportant. Now these, please do remember that, in fact, are going to determine your future career. But that is not all. What you are going to be, my young friends, depends upon what you are going to do in the next few years to come. Alas! It is often very true that people get a degree, get a job and perhaps get married, and

then forget all about what they learned in college. That is hardly the thing to do. If you are all going to be worth any little at all in the future, it can be only if you remember what has been laid now as the foundation in these four or five years. On that foundation you must build.

You always have to remember a few things, you will permit me to remind you of them. This most wonderful possession that you all have, everyone of us has, is this human body. It is our parents who gave it to us. I have recently turned my attention from physics and chemistry, mineralogy and mathematics to the study of the human faculties. Some of them, unfortunately, are hidden away inside the brain and we have to take them for granted. The mere study of all these external points of contact has made me realise what an amazing possession we have.

There is another little thing that we all forget very often. There is a little thing called the 'heart'. That little machine started working when you were born, why even before you were born and goes on ticking at a certain rate and it goes on ticking, ticking, ticking all the time at the same rate, at nearly the same rate, all the time when you are young and all the time when you are getting to be an old man, until you are dead. And when that stops, you are dead. That wonderful machine, my dear young friends, has to be safeguarded. You often hear of great men suddenly dropping down, their doctors call it coronary thrombosis or whatever other names, learned names for this collapse which causes death. And why is it that this happens? It is because they over-drive this wonderful machine. They misuse their bodies. They think, now that I am so young and energetic, I can do anything I please, I can eat all the chillies I want, go out all night, attend theatres, friendship parties and so on. And what happens? No doubt the young blood can stand the strain, but it tells. And what happens then? You are prematurely aged and then coronary thrombosis comes in and takes you away. I want you to realise this at the time of youth. This is a lesson I have learned myself. Please do not think that I am preaching what I don't practice. I have always practiced it. I believe not in precept but in practice. Always, I believe that the greatest influence that a teacher has is, as they say, by his example and not by his perception

only. Now is the time when you are still young, when the blood is still flowing warmly in your veins and arteries, now is the time to improve on what you learned here.

India has an enormous population. We are all trying to make India great. But who is going to make it great? It is only the young intelligentsia of the country. Realise it is up to them to use not only their hands but use their brains to learn to think. The faculty of independent thinking must be applied to all problems of life. You must be serious about life. You must not think that hasty pleasures or indulgence in all sorts of loose things are going to help you at all. This is the lesson that I have learned in these sixty years of life, actively as a man of Science. There is nothing that makes a man so happy as some real achievement. It is the achievement of doing something real that has a permanent value and will be recognized all the world over. The money bags that you find in the Reserve Bank are nothing when compared to this achievement. The mere joy of achievement is something very great. And I think all our young people who come out of our Universities realise that it is up to them to see how best they can raise the glory of India and how best they can make themselves happy, how best they can achieve even material success. It is only by realising this while they are young, while they have energy, this will be possible.

I am almost inclined to enter into a dissertation on old age versus youth. I could speak for half an hour on that thesis, 'Age versus Youth'. You know that age is credited with wisdom. With all deference to the people around, I beg to question that proposition. I tell you what youth brings along with it. If you do not take care of yourself, you are left with creaky bones, your teeth drop out, your eyes become blurred, your ears become half-deaf and, worst of all, you become cynical, contemptuous of others. You come to think life is not worth living. And, in fact, you come almost to such a stage that but for the unfortunate desire we all have to continue to live, the easiest plan would be to swallow a tube of morphia and be done with it all. We do not feel like doing it and that is because God has implanted in us an absolutely unhealthy desire to continue life in spite of these miseries. I tell you that because it is very, very difficult indeed to summon up,

as you grow old, those enthusiasms, those fears, desire for, achievement, energy and all that. Youth is the most glorious time of all. I have said elsewhere that most of the great discoveries in Science have been made by young people. It is not the experience or wisdom that old age brings, but the freshness of outlook, the indomitable desire to achieve, which is the characteristic of youth, that makes discoveries possible. It is this that makes life worthwhile. If only you realise this and realise that here I am, I am still young, let me see what I can do, that all discoveries become possible.

Fearlessness and independent thinking

And above all, in my own experience, I have found that one of our evils is that for centuries we have been trodden under the feet of conquerors from abroad. I don't want to recite all their names. One of the things that has been bred in us, a very deep and ineradicable defect, is a kind of inferiority complex which makes us think that we dare not question what has come to us from abroad. Whatever comes to us in a textbook must be right, some great man has said something, well, we must bow to him in fear and trembling and never question him. This produces a mental inhibition. Now, I do not suggest to you that you should all become arrogant, contemptuous of all the great men of the past. Not at all. I am not suggesting that. But I think we should all learn that no one is infallible. Not even Hermann Von Helmholtz, not even Einstein. Nobody is infallible. New knowledge may upset what may have been made in the past, and may completely throw out what has been done before.

So I think one of the things all Indians should learn is fearless independence of thinking. That is a quality which is very essential and the absence of which, if I may venture to say so with all deference, is what stands today in the path of Indian progress. Whenever we want to do anything, we borrow money from abroad. We all know that every day we see one hundred million dollars or one billion dollars being borrowed from somewhere. Our so-called independence freely consists, if I may say so without entering into politics, in our being ruled by

a consortium of all the nations in the world, except ourselves. Leave that alone. Bad enough to borrow money. But what about borrowing knowledge? What about borrowing experts from abroad? What about forgetting to think for ourselves? This feeling of helplessness must be shaken away, shaken out ruthlessly. We must realise that we must stand on our own legs. It is better to work with the most inefficient useless equipment of ours than to shine in borrowed feathers, better to work on problems with our slender resources. We must realise this and until and unless we realise this, we cannot go on. And I want to turn to my great industrialist friends who want to buy know-how at great expense from abroad. Let me assure them that they will never get on and get very far. You see that the signs are already there. The rupee has come down, I do not know to how many cents, and Mr. Masani has said that it will soon come down to five cents. I am not wishing that his prophesy comes true.

Science and Technology progress

But no country, and as you are all engineers, let me express here forcibly my conviction that no country can become industrially great without a foundation of real knowledge. This is what Science teaches. Science has shown time and again that Science comes first and Technology afterwards. Without Science, there is no Technology. Why has Germany been so great? Because in the 19th century, she had a galaxy of men of Science in every branch of knowledge, whose name and fame shone forth. Because they were not technicians, they were humble professors in the universities. But they sought knowledge and they made their students seek knowledge. They were springs from which knowledge came forth, gushed forth and it was that knowledge, that spring of knowledge, that fertilised all the industries of Germany and made her great.

It is realised in all countries today, that Science comes first and Technology afterwards. If you think you can build a great industrial nation, make tons of money and pay off all these awful debts by pursuing so-called Technology alone, you are doomed to complete failure. Let

me say this without hesitation. It is only when we set our houses in order and build up powerful schools of thinking in every field, electricity, chemistry, metallurgy and so on, only then we will have the solid basis of knowledge from which can come forth men who will teach your technologists what to do. I think it is true to say that the finest instruments, the most sophisticated instruments, are not found in technological laboratories, but are found in the research laboratories where men are trying to explore the unknown world and try to discover things. There is also another thing which is well worth remarking upon and that is, in not a few cases, not only is Science the fountain-head of technological knowledge. In many cases Science has set the problems which the technologists had to solve.

You may recall the history of Astronomy of the 19th century. Astronomy is usually regarded as one of the useless subjects. Our ancients were much concerned about the stars because they thought that the sun and the stars had something to do with human affairs. So they very keenly watched the planets and the stars. Though the reasons they may have done so may be wrong, there is no doubt that the pursuit of astronomy is of infinite importance to us. The study of astronomy may look as if it has nothing to do with human affairs, if you do not believe in astrology, but really it is more from the study of the stars that you have learned more about the earth we live in, more about the Sun and more about everything, than from the study of terrestrial sources of light. The astronomers demanded instruments of the highest precision with which alone they could follow the movement of the stars, do the time-keeping, note the displacements, aberrations. parallax and so on. The demands of precision instruments, especially by Germans like Bessel and others, led to the modern development of precision mechanics. You understand what I mean by precision mechanics. I wish to mention the fact that the great telescope at Palomar, the 200-inch telescope, that enormous thing, that tremendous, huge, massive thing, hundreds of tons in weight, has to be moved with the accuracy and precision of a Swiss watch and nothing less. Nothing less will satisfy the astronomers. This huge mass has to go round with

the smoothness and precision of a Swiss watch. I know what the precision of a Swiss watch is. I have got here a watch on my wrist which I wear only on occasions such as this. Well, I want to be reminded of the time which passes and I wind it only about once a year or so. But all the time it shows the correct time. Astronomy demands such precision and it was the demand of the astronomers that led to the development of precision mechanics which, of course, today we use in everything.

You can quote example after example to prove this. The demands of Science, the botanist, the zoologist who wanted to examine his subtle structures led to the development of the great firm of Carl Zeiss. It was Ernst Abbe who took up that problem and made the optical industry what it is today. What was demanded and made for the needs of Science has benefitted everybody else. The same story is repeated in all the beautiful instruments that have gone to make this great advancements of knowledge possible in these sixty years. They were born out of the brain of men of Science, they were translated into practice and today they are the tools of study in every branch of knowledge. Every metallurgist today uses the electron microscope. Who thought of it? A man of Science who was not interested in its possible applications. He was interested in it for its own sake.

Now I wind up. I think I have gone on long enough. I must stop. I know you are all listening to me with great eagerness and interest. I must put an end to your agonies. I will do so as soon as I can. But this I would like to say, that the developmemt of knowledge and Science in the last sixty years, I have seen from the inside. I have not been inside all the time, but I have been inside most of the time. It has been something absolutely fantastic.

The nature of scientific advances

Why is it that Science has developed in such an explosive or spectacular fashion in the last sixty years? There are really three causes. We can analyse them and put them apart. First and foremost stands the fact that towards the end of the 19th century, or in the beginning

of this century, came a succession of epoch-making discoveries in fundamental knowledge, the discovery of the quantum of action by Planck, the discovery of Einstein of the corpuscular nature of light and then the use of this principle by Neils Bohr and others to analyse the structure of the atom, to explore the chemical molecule. This sort of explosive development at the beginning of the century made a terrific advance possible, in the study of the ultimate structure of matter, and this explosion is still going on.

There is a second and a great stream of scientific knowledge which has come out in this way. And that is the fact that Science, as we all know and recognise it, has very definite applications to human welfare. This is most evident from examples in the field of agriculture, the knowledge of heredity, the Laws of Mendelism and so on. They made a great difference to the science of agriculture. So also, one of the most important advances which has a bearing on the work of you gentlemen is the discovery of what is known as plastics. The whole science of micro-electro chemistry as it is called has developed from the work of a man who was interested simply in studying the big molecules, Staudinger. Then the subject took on an explosive development. Today we can't live without plastics. We drink our coffee out of plastic cups. We wear artificial silks made of nylon and plastics. It is a typical example of how pure Science has led to the development of vast industries with the greatest possible importance. Then we have also examples in medicine. From ancient times, the human body has been subjected to all kinds of illnesses and the 'medicine men' with their drugs did a roaring practice. The modern expression with regard to those funny people calls them 'witch doctors'. From the medicines of these witch doctors to the modern medicines, the leap has been marvellous.

But there is a third and a most sinister way in which Science has developed in the last sixty years. And that is Science in its applications to war, application to defensive war and offensive war. Even in medicine, much of our knowledge of the human brain has come from the study of half-dead and half-dying men in war. The examination of

their bodies has led to a profound advance in medical knowledge. So war has had that result. I think we can say that a lot of modern Science has really come directly out of the needs of war. I knew for example, in the First World War, men like Lord Rutherford, Sir William Bragg and many other British scientists were all busy trying to combat the submarine menace by the invention of the subsonic devices that, today, are being used everywhere. Even in the First World War, the use of aviation in warfare was already being developed; in the Second World War it took a tremendous turn.

And not only that, the Second World War, as you all know, brought the atom bomb into existence. That atom bomb has come directly out of the consequence of the actual discovery of fission made by Joliot Curie in the laboratory — he showed it to me when I was there in Paris, the gist of the discoveries made. That immediately set thinking minds in action — here is an instrument of dreadful power, if we use it we can destroy mankind. And fear, the fear that the other man may use it led to the development of the atom bomb everywhere. Then the hydrogen bomb came. And ever since, an atmosphere of fear, it is a horrible thing to see, an atmosphere of fear of mutual recrimination, progressive deterioration is there, like what happens to a man when he borrows money. You see the interest goes on adding up. It becomes a colossal figure, which bears no resemblance whatsoever to the loan which he took at first. This kind of explosive development of fear complex has produced a psychological, a pathological state of affairs in the human mind in which all evils thrive and sustain. Today, Science in many countries is simply the hand-maid of the war machine.

Wonderful achievements, rockets sent up and two men jumped out of it and had a rope tied to their bellies and they walked in space. And everybody says: 'Oh! What a great feat!' Let me tell you, I simply smile with loathing and contempt. It is with feelings of loathing and contempt with which I witness this colossal display of lunacy on the part of mankind. It is nothing less than lunacy, sheer raving lunacy, to spend billions of dollars. Instead of shooting two men into space

they could have shot two monkeys and made them walk in space. It is just a mere pretence. I say this with all sense of responsibility, it is a mere pretense to say that all these exploits of finding out what exactly is there on the moon and so on, have any scientific value whatever. I absolutely deny that. It is nothing but militarism very thinly disguised. That is what is happening today. It is very sad. Our Science is going that way. So Science today is misused.

I heard the pledge given by you, that you will not use your knowledge for unworthy ends. If you had been in one of those countries you would have to use it for unworthy ends. Otherwise you would lose your job forthwith. What is the use of giving a pledge which you would have to break in order to get your daily bread? This is what is happening today. There are sensitive consciences even in those countries who revolt from this sort of thing. But it is going on, going on, this prostitution of Science. Where it will end, I do not know.

Only I want to say this, that we in India to some extent are slaves. We are part of the machinations of our so-called friends. We are forced to accept this situation. Our friends in the United States give all the latest arms to our friends in Pakistan and they want them to use these against us and they have used these against us and we are forced to reply in time. The Russians thought that the Chinese were a friendly nation. They taught Chinese all the arts of war. What China is doing today is what Russia had taught her to do, and now China is paying her back in her own coin. This is a horrible situation. I do not know what to do. As a man of Science, my heart is simply wrung with this amazing prostitution of Science. We can do nothing about it. In fact, we have to accept the situation as it is and do what we can. I am sorry to have had to end on this very unfortunate and depressing note. There it is.

Self-reliance, the need of the hour

But let me end by saying that we in this country have no future whatever of any sort unless we learn firstly, secondly and lastly to rely on ourselves for everything that we need. It is better, I think, to go back to

the Gandhian age and ride an ox-cart, to throw away radio, television and everything and go back to the land of the ox-cart. We cannot do it unfortunately. We are tied to the coat-tails of European civilisation, I include myself also in this. In the first place I put a big query mark after the word 'civilisation' and I must also put another mark after 'European'. I must also add American, you know the American way of civilisation. We are tied to their coat-tails. We find that we cannot be happy unless we have a radio making a lot of noise in the other room. I never listen to a radio. I simply loathe it. One of the things that we have been taught from childhood is to admire this wonderful flicker on the screen. I never go to a cinema, never. For twenty years I have not stepped inside a cinema theatre. I cannot advise my young friends to follow my example because I know they won't follow my example. We are told that we cannot be happy unless we have a television set to see some lady dancing on the television screen. This is the trouble.

You see our tastes have been corrupted. We do not want to look at the banyan trees. We must go and see the cinema screen. Now we must, I say this with all energy that I can command, we have to eschew all the evil things whlch we learn from Europe and America. Let us not condemn Science for that reason, but we must not subordinate ourselves to the ideas and ideals which have come to us from the West, which are simply designed to make us part with our rupees and make the rupee worth five cents, as Mr. Masani says.

If we cannot do these things ourselves, let us do without them, as I say, let us walk, let us go in the country carts. If we cannot make our motor cars, why should we buy them from abroad? Why even import parts? It is one of those funny things, it is said "Oh! 85 per cent is 'local made' and the remaining 15 per cent is imported". They talk of electronics. I have tried hard to find out if there is any one place — I have not yet heard an answer to that — if there is any place in India where the most important component of all electronic valves is made. All these depend upon the manufacture of a metallic filament which will stand the current. If they are being made in India I should like

to know where they have been made. I have not heard of any. That is the starting point of the whole electronic industry and do we make it? Let us wait till we can make it, before we buy a single electronic valve from outside. If we do that, then I think we would learn, how to make it. It is this lesson of self-reliance that we have to learn and until we learn it there is no future for us."

This address, spoken from the heart, defines Raman's views on a wide range of topics and issues. No one in India of his stature expressed his views so fearlessly as Raman did.

Intensely national, Raman spoke in no uncertain terms of his abiding faith in the younger generation and this made him feel not so desperate about the 'brain drain' as others. The proper attitude of Science and scientific research was to him more important than fancy laboratories. Once he remarked: "The essence of Science is independent thinking, hard work and not equipment. When I got my Nobel Prize, I had hardly spent Rs 200 on my equipment. See my 'Physiology of Vision' research. All the equipment with which I worked for this book is here in my table drawer, devised by me." On the occasion of the opening of a laboratory he asked cryptically: "Where are the brains to put into this magnificent building? Remember, Radium was discovered in a tin-shed!"

Raman's contributions to Science in India

Raman was a great builder of institutions and centres of research. He revived and revitalised the Indian Association for the Cultivation of Science and established the Departments of Physics at the University College of Science in Calcutta and at the Indian Institute of Science, Bangalore, and founded the Raman Research Institute, making them all centres of world renown. He recognised the importance of scientific journals and started one in Calcutta under the Indian Association for the Cultivation of Science, which later became the *Indian Journal of Physics*. When he moved to Bangalore, he founded another journal called the *Proceedings of the Indian Academy of Sciences*. He was also actively involved in the starting of *Current Science* in 1932, which was styled after *Nature*. He believed strongly that the

best work done in India should be published in Indian journals, and set a personal example by publishing all his papers in the journals he started. Raman's, as well as the work of his students, fill the pages of the *Proceedings of the Indian Academy of Sciences*.

Recognising that a scientific forum was necessary to bring awareness of Science to the layman and to the Government, he founded in 1934 the Indian Academy of Sciences, to which outstanding scientists from all over India were elected as Fellows. The *Proceedings* that issued from the Academy and its annual meetings were regular features. Raman was elected its founder President and he held the office until his death in 1970. He also served as the editor for the *Proceedings* and set the highest standards for the journal. The *Proceedings* came out promptly every month in two sections, A and B, for physical and biological sciences respectively, and were dispatched to all the subscribers in India and abroad. The *Proceedings* of the Academy were considered as being among the top journals of the world.

The lofty ideals with which the Indian Academy of Sciences was started and the *service to the nation* which it was expected to render were eloquently described by Raman himself at its first annual meeting in Bombay. On that occasion he said:

> "I think it would be not inopportune to consider at this stage the nature of the services which the Academy can render to Science in India. We live in an era of scientific progress and it is a very gratifying feature that India is beginning to pull its weight in this respect. Modern scientific progress shows side by side two apparently contradictory features. On the one hand, we have an enormous accumulation of raw scientific material, the significance of which, in many cases, is hardly apparent except to specialists in very limited fields of investigation. On the other hand, we have a great process of scientific synthesis going on, tending towards the simplification and unification of the fundamental principles of natural knowledge in all its ramifications. It should never be over-looked that Science is in reality a great impartible estate and that the boundaries drawn across it to divide it

into restricted fields are in essence artificial. I think the history of Science has shown over and over again, that it is only by boldly cutting across these artificial boundaries that progress of real significance can be achieved. It is precisely this feature that lends importance to the activities of such an Academy as ours, where men of Science of widely different scientific interests come together in a common endeavour and seek to understand each other's point of view.

While specialisation is necessary, an excessive narrow outlook defeats the primary purpose of Science, which is to advance our essential comprehension of nature as a whole. It is, therefore, one of the most important functions of our Academy to promote co-operation between men who profess knowledge of different branches of Science. This is effected in various ways. In the *Proceedings of the Academy*, the Fellows and, indeed, all scientific men have an opportunity of obtaining at least a general idea of what is being done in India in fields of knowledge other than their own specialty. In the scientific meetings of the Academy and especially in the symposia they have a valuable opportunity of discussing problems of common interest from different points of view.

I will also say a word about the Academy, in relation to the nation at large. It is inevitable that the Academy, consisting as it does of the most active workers in the country who are representatives of the different parts of India and of different branches of Science, will soon come to be regarded as the most authoritative body to speak in the name of India on all matters touching the progress of Science. The potentialities of such an Academy in the way of national service are almost unlimited. What it can actually achieve depends on the measure of support it receives from the Government of India and from the general public. I do not think that any calls for service from responsible quarters will find us unwilling or unprepared."

With the passing away of Professor Raman, the Indian Academy of Sciences and its *Proceedings*, with their well-established scientific traditions, have passed into the hands of other Indian scientists as two of his most valuable legacies to them.

Raman took a personal interest in all the affairs of the Academy; publication, meetings, elections and actual running of the organisation. He had the trusted and loyal assistance of B. S. Venkatachar in managing the day-to-day affairs of the Academy. The Academy office was located in the Raman Institute campus and Raman would walk to the office almost every day to discuss matters concerning the Academy with Venkatachar. The principal activity of the Academy was the publication of its journal, the *Proceedings*. Most of the papers published in the *Proceedings* were scrutinised by Raman himself for scientific merit, importance and presentation. He was very particular that the journals were brought out promptly at the end of each month and mailed to the Fellows and subscribers on the first of every month.

Raman took a very keen interest in the election of Fellows to the Academy and, in those days, the number of Fellows elected would, at the most, be half a dozen. Raman personally looked into the nominations and discussed the merits of the candidates at the Council meetings which usually made the recommendations to the General Body. Raman himself proposed candidates if he felt that the persons concerned were active research scientists showing promise for the future.

One fine morning in 1954, he came to me and said, "I am proposing you for election as a Fellow of the Indian Academy of Sciences". I was taken aback and told him, "Sir, how do I deserve such an honour at this point?". His reply was: "I know how to judge people and when to honour them and encourage them. I don't recommend anyone who does not deserve the honour." I was elected that December as a Fellow of the Indian Academy of Sciences.

In 1956, the Treasurership of the Academy fell vacant and, at Raman's suggestion, I was installed as the Treasurer, in which capacity I served until I left Bangalore. By virtue of this office I was also a member of the Council of the Indian Academy of Sciences, which shaped the policies and activities of the Academy under the stewardship of its President, C. V. Raman. During my tenure I had the pleasure of sitting with some of the finest people in the scientific field in

India, including S. Bhagavantam, who was at that time Director of the Indian Institute of Science, M. V. Govindaswamy, Director of the Bangalore mental health hospital and who himself was a clinical psychiatrist, B. S. Madhava Rao, Principal and Professor of Mathematics at Central College, Bangalore, B. K. Narayana Rao, a well-known ophthalmic specialist in Bangalore, C. S. Pichamuthu, Director of the Mysore Geological Survey, and L. Rama Rau, a palaontologist and retired Professor from Central College.

Raman presided over the Council meetings and it was a pleasure as well as a great experience to hear him at these sessions. He would, of course, dominate the floor at the meetings which were attended by half a dozen Councillors. Good tiffin and excellent coffee were served and relished by everyone at these very enjoyable meetings. Raman got whatever he wanted from the Council and the meetings always ended on a happy note. At one of these meetings, Narayana Rao made the suggestion to Raman that younger people should be brought into the Council. I remember very well Raman's remarks. "Dr Narayana Rao, nothing like old shoes. They are very comfortable and do not bite your toes and cause you trouble. I prefer wizened, grey and mature heads, preferably wearing a turban." Both Raman and Narayana Rao wore turbans. Everyone had a good laugh.

Raman organised the annual meetings of the Academy meticulously, with scientific programmes and public lectures. The best work done by the Fellows and their associates were presented at these meetings at which Raman's public lectures were usually the high points. The Academy met at the invitation of a University serving as the host, so that young students of Science got exposed to the scientific body and heard India's foremost scientists in person.

I attended ten of these meetings. Raman would sit through all the sessions, covering both physical and biological sciences, and added lustre and humour to the proceedings. He would ask the most penetrating questions and make very entertaining comments. It was dangerous to give a talk before him that had no originality, for he called a spade a spade right in front of everyone. These annual meetings

were jocularly referred to as 'Raman's circus'. He never failed to be present at these meetings, except once towards the end of his life. The Indian Academy of Sciences has redoubled its activity and its publication efforts have multiplied several-fold in the post-Raman era.

In assessing Raman's place in Indian Science, the following quote from a jubilee volume which was published in 1938, to felicitate him on his 50th birthday, might be considered a pointer. At that time, he was practically at the peak of his scientific fame, having achieved his ambition of creating a strong school of modern Science in India.

> "He is the outstanding figure in the renaissance of Science which has been taking place in India during the last quarter of a century, and indeed with truth he may be designated as the creator and leader of that renaissance. The progressive enthusiasm for scientific studies and research which is witnessed on all sides in India today has largely been inspired by him and encouraged and sustained by his efforts.
>
> The personal example of his dedication to a scientific career, the brilliance and originality of his researches, the international character of the recognition which his work has received, his success as a teacher in training investigators who are now themselves guiding schools of research, his gift of eloquence which has served to stimulate a widespread interest in Science, his achievements as a scientific administrator in creating facilities for research and establishing new schools of Science, and his success in founding journals for publication of scientific work in India, are among the factors which have profoundly influenced the progress of Science in the country."

This Summary in 1938 about Raman's contributions to Indian Science proved even truer in the years that followed.

Towards the end, Raman turned somewhat bitter and cynical about politics in Indian Science and scientific development in the country. He shunned all the activities of present-day scientists in India. He did not believe in big scientific organisations and was suspicious of scientific administrators. He used to say, "For such people, the so-

called organisation of Science becomes more important than Science itself, or its values". But to the very end he never gave up his interest in pursuing his own scientific activity or of trying to arrange for the future of his Institute after him.

Prof. Ramaseshan, his nephew, who was at the National Aeronautical Laboratory in Bangalore, became quite close to him during his last few years and Raman often discussed the future of the Raman Institute with him. After Raman's death it was his wish that the Directorship of the Institute be offered to his son, Radhakrishnan, a well-known Radio Astronomer. Ramaseshan took a very active role in carrying out Raman's wishes.

Raman was a staunch nationalist and was proud of his Indian heritage and its past achievements. He admired Mahatma Gandhi and Jawaharlal Nehru, although he did not agree with all their policies. In the matter of scientific research, he insisted that Indian scientists should not be camp-followers and imitate what was being done in the West. He often proclaimed that what one did should not only be original but should also be relevant to India's needs when it came to application of research. He was opposed to Indian scientists going abroad for advanced research and believed that it impeded originality of thinking. It is difficult to say whether he was right or wrong, but it is a fact that independent India is yet to produce scientists of Raman's calibre, although the money spent on scientific research is enormous compared to the Raman days. Raman may have had a point.

Raman was a man of emotion and could get violently angry. But he had an incredible sense of humour and could keep an audience roaring with laughter merely describing what would have been a commonplace incident. Above all, he was a very simple man, quite childlike, sometimes even childish. There was a condolence meeting in Bangalore when Einstein died. When Raman got up to speak, he was choked with emotion and sobbed like a child before he could talk.

Anyone who met him could not but be struck by his zest for life. His exuberance was infectious. Chatting with him for some time was

like taking a tonic. To him, scientific activity was the fulfilment of an inner need. His approach to Science was one of passion, curiosity and simplicity. Science was to him a personal endeavour, an aesthetic pursuit, and, above all, a joyous experience.

No single person has done so much for Indian Science as Raman. Through personal example of the highest dedication to Science, through his success as a teacher-cum-leader in training generations of physicists who in turn have created independent schools of research, through creating scientific institutions and facilities for research and founding scientific academies and journals for the dissemination and propagation of Science, and through his gift of eloquence which served to inspire and stimulate a widespread interest in Science, Raman, as a single individual, tremendously influenced the progress of Science in India.

He was one of a rare breed of men who are no more, who ranged freely in all fields of science from physics to chemistry to biology. Raman stands alone as the greatest scientist that India gave the world. The poet Valmiki, describing the battle between Rama and Ravana, said in the great epic, the *Ramayana*, "The sky is comparable only to the sky, the ocean only to the ocean and the battle between Rama and Ravana only to the Rama Ravana *yuddham* (battle)". In modern India, Raman is comparable only to Raman.

Chapter V

Lady Raman

A few remarks about Lokasundari Raman will not be out of place here. Those who have known her have often admired her devotion to her husband. On several journeys, she used to travel with him and look after him. Her principal interest in life was only one and that was to enable Professor Raman to carry on his scientific work in an uninterrupted manner. Seldom did she permit the projection in public of her own personality distinct from that of her husband's. This aspect of hers, besides being in accordance with the best of Indian traditions, was so noticeable on occasions that she drew the admiration of all concerned.

Lady Raman was of gentle nature. She moved around with grace and dignity, dressed always in simple sarees and with practically no jewellery. She spoke several languages; Tamil was her mother tongue, but she could speak Bengali fluently. She could also converse in English, Telugu, Kannada and Hindi. She was active in many social organisations devoted to the causes of women, children, the depressed and the poor.

There was a discussion (in the early part of 1936) between Mahatma Gandhi and Lady Raman which reveals her nature and her interests. Gandhiji is reported to have told Lady Raman that he would be willing to visit the Institute of Science if Raman would be willing to show him some magic there! He also said to Lady Raman: "I have

heard all kinds of good things about you from your husband, but I have to find out how far they are true. He told me the other day that whilst he is absorbed in his Science, you find time for all kinds of humanitarian activities."

Lady Raman replied: "Not as much as I should be doing. But I am certainly interested in Khadi and Harijan welfare and social service and things of that kind. You know, Mahatmaji, I have been a spinner for many years. Some fifteen years ago I sent you a quantity of my own hand-spun yarn to be woven into cloth, and the late Madanlal Gandhi sent the cloth on to me. But my husband had no faith in the wheel then. He would put away my wheel, smash it and break it; but I am glad to tell you that in my own lifetime the day has come when he no longer ridicules the wheel. He too believes in it."

Gandhi said: "I am very happy. Well, then, I want you to do a little work for me. Did you ever meet the late Kamala Nehru?" Lady Raman replied" "Once or twice, Mahatmaji. But I know the old Mrs. Nehru very well." Gandhi said: "But you, of course, know what a good woman Kamala was. You know how she spent herself for the country. But when I prize most of her is not her political contribution, but her great spiritual beauty which I should like every man and woman to know."

Lady Raman butted in, "Yes, I know of her services and her moral beauty".

To which Gandhiji said, "Then you must help me in collecting some money for the Memorial we are having for her".

Lady Raman heartily agreed. As this dialogue was going on, in came Sir C. V. Raman. She was talking in Hindi as he came in. "Now, is that Hindi any good?" he asked jocularly, to which Gandhiji replied, "Certainly as good as your Science".

"Oh, yes", said Raman. "She has an amazing capacity for picking up languages. She knows Hindi, she knows Bengali better than Hindi."

Gandhiji put in, "Of course, she has stayed in Calcutta for some years".

Raman replied: "Not necessarily for that reason. I, too, have stayed with her. But I know not a word. And now, here, she has picked up Kannada and talks it." Raman then began wondering what language could be the language for the masses of India and seemed for a moment to incline towards English (*Harijan*, 6.6.36).

Lady Raman's main interest was to take care of Raman; serving him with food at the proper time and compelling him to take sufficient rest. She managed her home very efficiently and always put her interests after her duty towards her husband. There was a person to take care of the kitchen, but Lady Raman was good at cooking and could very well manage by herself when the occasion demanded. She always had other persons in the house as well; often relatives and, quite frequently, someone, especially women, who needed help and shelter. She had a compassionate heart and took upon herself the task of helping the poor and the helpless.

Lady Raman was a self-educated person. By association with Raman and his vast coterie of admirers and students, she picked up a phenomenal amount of knowledge about various things. She could deal with almost any situation. Her account of Raman's trip to Stockholm to receive the Nobel Prize is replete with humour, fine details and marvellous descriptions. Raman often delegated to her the care of routine matters connected with the Institute. When it came to worldly matters, she was Raman's trusted adviser.

Once, she planned to take some visitors round the museum of the Raman Institute. I volunteered to accompany them and explain to the visitors the various scientific aspects of the exhibits, but she did not accept my offer and told me that she could manage by herself. However, I did accompany the party and found myself a silent spectator listening to Lady Raman doing an excellent job as she explained the nature of crystals, in particular the nature of diamond, in very simple language. The visitors were quite impressed with her commentary.

Raman's total absorption in Science must have been hard on her, for in later years, she turned somewhat cynical in her attitude. She could be absolutely charming, very helpful and very warm. But at other times her attitude would be different. Lady Raman loved

her two sons very much, but the older son, Chandrasekhar, had left the house, for his lifestyle and ideas were not consistent with Raman's. The second son, Radhakrishnan, also left India a few years after graduating in Physics from Mysore University, and spent a long time abroad before he returned to accept the Directorship of the Raman Research Institute. All these happenings turned Lady Raman somewhat bitter, but her devotion to Raman was in no way affected.

At the time of Raman's death, when his body was being removed from the Hall, she stood by and wept like a child. She said, "I took care of him for more than sixty years and you are all taking him away from which he will never return". It was heart-rending to see the grand old lady break down like this. She was, of course, a very strong person with a strong will, and recovered from the shock. When Radhakrishnan returned to Bangalore to assume the Directorship, she felt very happy and became her old self. During my visits to India between 1971 and 1980 I always called on her and she was very cordial. Lady Raman lived for ten years after Raman's death and passed away in May 1980. It was a great satisfaction to her to see her grandson born and Radhakrishnan firmly established in Bangalore as the head of the Raman Research Institute.

Kausalya Ramaseshan, Lokasundari Raman, Kamala Jayaraman

Lady Raman playing Veena
(Photo Courtesy : *Dominique Radhakrishnan*)

V. Radhakrishnan

Radhakrishnan, the second son of the Ramans was known to his friends simply as Rad. He was born on May 19, 1929, just after Raman discovered his Effect. My first contact with him was in November 1949, soon after I joined the RRI in Bangalore. In the large compound of 'Panchavati', Raman's residence in Malleswaram, Rad occupied a nice little cottage in the northwest corner, connected to the main bungalow and the kitchen-dining complex by a covered corridor.

Rad was very interested in electronics and had a lot of books and journals in the cottage, all neatly arranged, as well as a complete set of the magazine *Amateur Radio*. He was still a student at the Central College in Bangalore doing his B.Sc. (Hons.) course in physics when I first met him. Rad was very friendly to me and we used to meet frequently. I learnt a lot of electronics from him, for I was myself an amateur electronics enthusiast. Further, he introduced me

to astronomy and took me out to identify stars and constellations. In due course we got to know each other very well. After he finished his studies at the Central College he joined the IISc, Physics Department that was headed by Prof. R. S. Krishnan at the time.

However, he didn't stay there long. Around 1953, Prof. Rydbeck (from the Chalmers Institute of Technology, Sweden) who was doing important work in radio astronomy visited Bangalore. I remember his visit to our Institute very well, and he gave an excellent talk. Radhakrishnan and Rydbeck got to know each other well and out of that visit Radhakrishnan must have made up his mind to pursue radio astronomy. I think Rydbeck extended Rad an invitation to join his group, and one fine day Rad left Bangalore and went off to England. For a couple of years I lost touch with him. I don't know when exactly he joined Rydbeck's group, but I heard that he had done some outstanding work concerning radio emissions from Jupiter, a very significant contribution.

Soon after I joined UCLA, my friend Venkateswaran in the Meteorology Department told me that Rad was in Caltech and living in Pasadena. I got in touch with him and he was very cordial. He came to see me and took me to his apartment to spend a weekend. Over several South Indian meals that I managed to cook in his apartment with improvised ingredients — Rad loved Indian food — we caught up on things. During another visit he took me to the radio telescope facilities at Owens Valley and I spent two days with him when he showed me the huge dishes and how they collect data. I think he worked in the group headed by John Bolton, a well-known radio astronomer from Australia at the Caltech facility. I was fascinated by what all I saw. Rad also drove me to the neighboring San Gabriel mountains and for first time in my life I saw so much snow! We threw snowballs at each other and played like children. He also took me around Caltech and pointed out some of the famous people of those times. After my wife Kamala arrived in Los Angeles we used to invite Rad to our home on Levering Avenue in Westwood. He was fond of my daughters, and he also loved all the food that Kamala prepared. We always conversed in Tamil.

He then moved to New Jersey, to Bell Labs, to learn about microwave amplifiers. Derrick Scovil was an expert in the field, and Bell Labs had decided to help the Caltech group by building a microwave amplifier, then a very sophisticated device. I think Rad spent something like a year in Derrick's group and learnt all about operating the amplifier which he incorporated in the Owens Valley facility. During his Bell Labs days I visited him, and he helped me meet some people there. I was fascinated with the laser programme, as well as the large number of renowned scientists I had heard of. Again, our stay in his apartment gave us time to talk about my research in UCLA.

There was a break of seven or eight years before we met again. I knew that he went to Australia after Caltech and became very well known in the field of radio astronomy. In the meantime he got married to Dominique and came to the US with her — it must have been 1968 or 1969. They visited us at Murray Hill and were our guests for a few days. We enjoyed their visit very much except that Rad smoked a lot and I did not have the heart to tell him not to.

We then met in Bangalore in 1970, soon after the passing away of his father. I was spending a sabbatical year there at that time, setting up facilities for high-pressure research in India. Rad talked to me about the pressure being applied to him to accept the responsibility of running the Raman Institute. I told him he could do a lot of good for Indian science by accepting the challenge. He finally made the decision to move to Bangalore as Director of the RRI, and it flourished under his leadership for over two decades. Rad encouraged good research and set high standards for it, and his own scientific stature rose to new heights both in India and internationally.

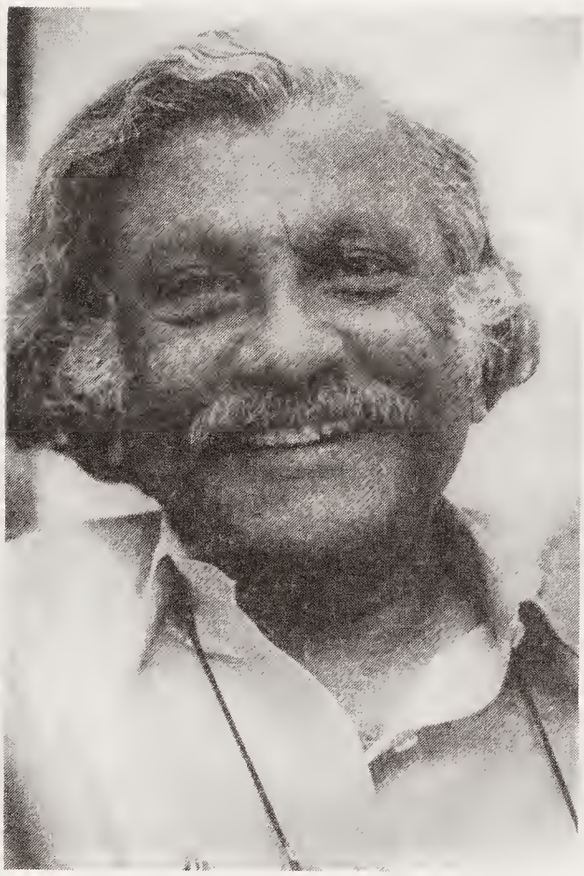
Rad's interests were very varied. He built flying machines and boats to sail long distances in hostile oceans! During one of our visits he showed me the flying machine and talked lightly about the near fatal accident he had and survived. He showed me the features of the 'catamaran' sailboat that he was building, and its modern navigation guidance systems. I was told that he did take it out to Cochin and

sailed in the Indian Ocean but things did not go well because of a storm and he had to abandon the trip.

The last time I saw him was in December 2009. He took me to his home and we had lunch prepared by Dominique. Earlier in his office we talked and at one point I became emotional when discussing Professor Raman, and his words were comforting. I learned with great sorrow that he passed away in Bangalore on March 3, 2011. I wrote a note to Dominique and she graciously responded despite her deep sorrow. She continues to live in Bangalore in the same house, perpetuating the memory of her great husband, just like Lady Raman did.

Rad was a chip off the old block in many ways. Fiercely independent, he treated people with due respect no matter where in the ladder they belonged. He listened to grievances of all Institute employees and was very fair in his dealings. So I have heard, and knowing his personality, I believe it to be true. He appreciated gifted individuals no matter whether they had degrees or not. He himself set an example by not going for any degrees.

Rad earned his status by outstanding accomplishments in his field. It was a privilege to have known him.



V. Radhakrishnan.

Rad with his family.

Dave and Rad tying up in Sydney in 1966.

Rad with his hand-glider.

(Pages 213, 214 Photos Courtesy : *Dominique Radhakrishnan*)

Raman's interest in music and musical instruments

The scientific work of both Helmholtz and Lord Rayleigh profoundly influenced Raman's thinking and research. In fact, Raman regarded Lord Rayleigh as his teacher in a very real sense, although he had never met him. Both these stalwarts had written marvellous treatises on sound. These books, which Raman had read in his student days, inspired him and, in the early days at the Indian Association for the Cultivation of Science, Raman took to research in acoustics. One of the aspects of sound he became deeply interested in was Indian musical instruments.

Music and mathematics have much in common, being essentially creations of the human mind. However, neither the mathematician nor the musician has generally cared to understand the world of the other. It was Pythagoras who felt at home in both spheres and was able to formulate what made a sound seem musical to the human ear. He discovered that the musical pitch of a vibrating string increased by an octave when its length was reduced by half, and from this developed his theory of harmony. If the string of an instrument was plucked, it not only emitted a note having a fundamental frequency, but also produced higher notes. The effect was musical if these overtones were in the ratios of 1:2:3:... etc. These harmonic contents were the ones that makes the note sound pleasing to the ear.

Raman began his first serious work in acoustics working on the theory of bowed string instruments. The vibrations of stretched strings fascinated mathematicians and physicists alike, not only for the wealth of the mathematical problems they provided, but also for the harmony of their tones. When Raman began his studies, the linear theory of vibrations of ideal strings was well developed, but, despite the existence of such celebrated violins as those of Stradivarius, there was little that could be asserted with adequate proof of how the vibrations of the strings of a musical instrument were governed or excited. In the course of his work on violins, Raman made fundamental contributions to the motion of the bowed point and the effect of the bridge in coupling the motion of the string to the body of the violin.

The work of Raman on the drums of India is epoch-making. The drum is amongst the oldest of musical instruments. Drums are to be found in almost all parts of the world in some form or other. The *tabla* and *mridangam*, two of the better-known percussion instruments of India, are of unknown origin and antiquity. They are unique among all drums, being the only ones that produce harmonic overtones, for the percussion group of instruments as a class can only produce anharmonic overtones and are, therefore, in a sense, only noise-makers. Raman perceived the musical sounds that emanate from Indian percussion instruments, and this excited him sufficiently to investigate the physics aspect of it. He showed that both the *tabla* and *mridangam* produced harmonic overtones and that this was achieved by the partial loading of the drum membrane with a firmly adherent but flexible paste. The harmonic overtones turned out to be the different modes of vibrations of a stretched but loaded membrane, which could be heard when appropriately excited. Raman was able to excite all these overtone modes by tapping the drum at the antinodes and restraining the motion of the drumhead by gentle constraints applied at suitable points with his fingertips. When he first discovered the harmonic character of these drums, there were no electronic oscillators or analysers; he had only his keen ear to rely on. Raman demonstrated the existence of these overtone modes by dusting the membrane with lycopodium powder and observing the pattern it produced on the excited membrane.

Decades later, the work on drums was taken up by Professor B. S. Ramakrishna at the Indian Institute of Science. Investigating with sophisticated instruments and methods of excitation, Ramakrishna and his coworkers confirmed all Raman's earlier observations and conclusions. They have, since then, presented a comprehensive treatment of the subject.

The *veena* and the *tanpura* are the oldest musical instruments of India and are revered as gifts of the Gods. Their tonal quality is perhaps the most pleasing to the ear. Raman made the discovery that certain overtones, which, according to acoustical principles, should be entirely absent, came out with great intensity in these instruments.

He showed that this violation of what is called the Young–Helmholtz law is due to the curved bridge which the ancient Hindus had discovered by experimenting and listening. The *veena* and *tanpura* could produce sounds richer in quality. The latter in particular is indispensable for Indian instrumental and vocal music, setting the reference for the artist; it is known as the background drone.

Raman's acoustical studies were not confined to Indian musical instruments alone; they extended to Western ones as well. We have already mentioned his work on the violin. His mathematical theory of how the impact of the hammer produces the exquisite vibrations in a pianoforte, and his demonstration of the peculiar Wolf note produced by the violin and cello were all classics, accepted and recognised by experts the world over. In recognition of his outstanding contributions in this field, he was invited to contribute to those famous volumes, *Handbuch der Physik*. In the Sixties, the Catgut Acoustical Society in America, a society devoted exclusively to the acoustics of violins, made him an honorary member.

Raman's interest in music was confined not merely to the strictly scientific aspects. He was familiar with South Indian classical music and had learnt to play the violin. Lady Raman was an accomplished *veena* player and was very interested in Carnatic Music. I often saw her at musical concerts in Bangalore and went to a few with her. However, I never saw Raman at any concerts. Once, we were driving through a part of Bangalore where the famous South Indian classical vocalist M. S. Subbulakshmi was singing at a wedding. Raman asked the driver to stop the car near the *pandal* so that we could hear her through the loud speakers installed outside. We listened for about fifteen minutes and then Raman asked the driver to move on. He said to me: "I say, Subbulakshmi's voice has changed now. Did you notice it?" I replied that it was so and that she had now become a full-fledged Carnatic vocalist; both her voice and style of singing were very different from when she sang film music.

In the late Sixties, Raman would occasionally arrange for a violinist, Thathachar, to come to his house and play for him. Lady Raman apparently arranged this at his request.

Raman's elder brother, C. Subrahmanya Ayyar, was a noted musicologist who could play the violin expertly. He had also written a book called *Grammar of South Indian Carnatic Music* in which he analysed the South Indian *raga* system, in terms of the notes and their frequency relationships which make up the melodic scale. This is an excellent monograph on the theory of Carnatic Music. C. S. Ayyar, as he was known, was an active participant in the technical sessions of the Madras Music Academy. The Academy holds its annual session during the last two weeks in December every year and the finer points of classical music are discussed by experts.

A strong interest in music ran in the family and it is no surprise that Raman became so engrossed in the acoustics of musical instruments and made such monumental contributions in this field.

The Raman Effect

To explain what the Raman Effect is to a layman is not easy. It is necessary to be an advanced student of Science to comprehend it. However, the lecture Raman gave announcing his discovery, under the title 'A New Radiation', is a masterpiece of exposition, set as it is in as simple a language as possible. This is a very important lecture historically and I am therefore reproducing it here for the benefit of readers.

There was also once a group of high school students from Tamil Nadu who came to visit the Raman Institute. There must have been 30 of them, led by two teachers. Raman took them round and, in explaining the crystals to them, he often broke into Tamil. The teachers who accompanied the group requested Professor Raman to explain to the students in Tamil what the Raman Effect was. Raman seated them in the lecture hall and explained to them in Tamil the nature of the Raman Effect. I was listening to the account he gave, for I was curious how he would go about it. The gist of what he said in Tamil would translate into something like this:

> "Think of a person throwing a tennis ball at a certain speed to a tennis player who is waving his bat back and forth. If the bat is moving

backward when the ball hits the bat, the ball will lose some of its speed and bounce back with a reduced speed. Similarly, when the ball hits the bat while the bat is moving forward, the ball will gain speed from the forward moving bat and bounce back at a higher speed than the thrower put in.

The Raman Effect has to do with light and molecules. You should think of the incoming light as the tennis ball thrown and the molecule as the tennis player who is moving his bat back and forth. The atoms in a molecule are vibrating constantly about the equilibrium position. Light also vibrates at a certain frequency (when it is monochromatic), and when it hits a molecule the frequency of the light is decreased or increased, depending upon the energy state of the molecule; the frequency of the light is increased when the molecule gives energy to the light, or decreased when the molecule takes energy from the light, like the ball gaining or losing its speed, as I've already stated."

Whether the students understood this analogy or not, it was a most apt way of putting it.

A new radiation[1]

Introductory

I propose this evening to speak to you on a new kind of radiation or light-emission from atoms and molecules. To make the significance of the discovery clear, I propose to place before you the history of the investigations made at Calcutta which led up to it. Before doing so, however, a few preliminary remarks regarding radiation from atoms and molecules will not be out of place.

Various ways are known to the physicist by which atoms or molecules may be caused to emit light, as, for instance, heating a substance or bombarding it with a stream of electrons. A light thus emitted is usually characteristic of the atoms or molecules and is referred to as

[1] Inaugural Address delivered to the South Indian Science Association on Friday, March 16, 1928, at Bangalore, and published in the *Indian Journal of Physics*, 1928, Volume 2, pp. 387-398.

primary radiation. It is also possible to induce radiation from atoms and molecules by illuminating them strongly. Such light-emission is referred to as *secondary* radiation. The familiar diffusion of light by rough surfaces may be cited as an example of secondary radiation, but, strictly speaking, it hardly deserves the name, being an effect occurring at the boundaries between media of different refractive indices and not a true volume-effect in which all the atoms and molecules of the substance take part. The first case discovered of secondary radiation really worthy of the name was the phenomenon of fluorescence whose laws were elucidated by the investigations of Sir George Stokes. This is a familiar effect which is exhibited in a very conspicuous manner in the visible region of the spectrum by various organic dye-stuffs. I have here a bottle of water in which an extremely small quantity of fluorescein is dissolved. You notice that when placed in the beam of light from the lantern, it shines with a vivid green light, and that the colour of the emission is not altered, though its brightness is changed by placing filters of various colours between the bottle and the lantern. A violet filter excites the green fluorescence strongly, while a red filter has but little effect.

Another kind of secondary radiation whose existence has been experimentally recognised more recently is the scattering of light by atoms and molecules. It is this scattering that gives us the light of the sky, the blue colour of the deep sea and the delicate opalescence of large masses of clear ice. I have here a large bottle of a very clear and transparent liquid, toluene, which, as you notice, contains hardly any dust-particles, but the track of the beam from the lantern passing through it is visible as a brilliant blue cone of light. This internal opalescence continues to be visible even after the most careful purification of the liquid by repeated distillation *in vacuo*. A similar opalescence is shown, though much less brightly, by dust-free gases and vapours, and also by solids. A large clear block of ice shows a blue colour in the track of the beam when sunlight passes through it. The blue opalescence of blocks of clear optical glass is also readily demonstrable. The molecular scattering of light is thus a phenomenon common to all states of matter.

During the past seven years, the scattering of light in transparent media has been the subject of intensive experimental and theoretical investigation at Calcutta, and it is the researches made on this subject that have led to the discovery which I shall lay before you this evening. One important outcome of our researches has been to show that while light-scattering is in one sense a molecular phenomenon, in another sense it is a bulk-effect having a thermal origin. It is the thermal agitation of the molecules which causes them to be distributed and orientated in space with incomplete regularity, and it is the local fluctuations in the properties of the medium thus arising which give rise to optical heterogeneity and consequent diffusion of light. The subject of light-scattering is thus a meeting ground for thermodynamics, molecular physics and the wave-theory of radiation. That the combination of theories in such diverse fields of physics gives us predictions, which have been experimentally verified, is one of the triumphs of modern physics.

A new phenomenon

While the quantitative investigations made at Calcutta have in the main substantiated the thermodynamic-wave-optical theory of light-scattering, indications appeared even in our earliest studies of a new phenomenon which refused to fit in with our pre-conceived notions. Thus, in some observations made by me with the assistance of Mr. Seshagiri Rao in December 1921, it was found that the depolarisation of the light transversely scattered by distilled water measured with a double-image prism and Nicol increased very markedly when a violet filter was placed in the path of the incident-light. More careful investigations, made with dust-free liquids in 1922, confirmed this effect and showed it to exist also in methyl and ethyl alcohols, and, to a lesser degree, in ether. It was also noticed that the colours of the scattered light from the different liquids studied did not match perfectly.

An important advance was made when Dr Ramanathan, working at Calcutta in the summer of 1923, investigated the phenomenon more

closely and discovered that it was not a true dependence of the depolarisation on the wavelength of the scattering radiation but was due to the presence in the scattered light of what he described as "a trace of fluorescence". This was shown by the fact that the measured depolarisation depended on whether the blue filter used was placed in the path of the incident-beam or of the scattered light, being smaller in the latter case. Accepting the explanation of the effect as "weak fluorescence", it naturally became important to discover whether it was due to some impurity present in the substance. Dr Ramanathan tested this by careful chemical purification, followed by repeated slow distillation of the liquid at the temperature of melting ice. He found that the effect persisted undiminished.

The investigation of this species of 'weak fluorescence' has, ever since 1923, been on our programme of research at Calcutta. Krishnan, who investigated 60 liquids for light-scattering in the spring and summer of 1924, made systematic studies of the phenomenon, and found that it was shown markedly by water, ether, all the monohydric alcohols and a few other compounds. He pointed out that the liquids which exhibit the effect have certain family relationships amongst themselves, and that they are also substances whose molecules are known to be polar. The chemical importance of the subject led to Mr S. Venkateswaran attempting to make a fuller study of it in the summer of 1925, but without any special success. The research was discontinued at the time but was resumed by him later in the current year (January 1928). The remarkable observation was made that the visible radiation which is excited in pure dry glycerine by ultraviolet radiation (sunlight filtered through Corning glass G. 586) is *strongly polarised.*

The possibility of a similar effect in gases and vapours was also borne in mind and repeatedly looked for by the workers at Calcutta. The feebleness of the scattering in gases and vapours, and the infructuousness of the earlier efforts in this direction, however discouraged progress.

Its universality

Though the phenomenon was described in the paper of Dr Ramanathan and Mr Krishnan as a "feeble fluorescence", the impression left on my mind at the time was that we had here an entirely new type of secondary radiation distinct from what is usually described as fluorescence. The publication of the idea was however discouraged by the belief then entertained that only a few liquids exhibited the effect and by the supposition that it was unpolarised in the same way as ordinary fluorescence in liquids. Indeed, a chemical critic might even have asserted that the effect was in each case due to a trace of dissolved fluorescent impurity present in the substance which our efforts at purification had failed to remove.

Early this year, however, a powerful impetus to further research was provided when I conceived the idea that the effect was some kind of optical analogue to the type of X-ray-scattering discovered by Prof. Compton, for which he recently received the Nobel Prize in Physics. I immediately undertook an experimental re-examination of the subject in collaboration with Mr K. S. Krishnan and this has proved very fruitful in results. The first step taken in the research was to find whether the effect is shown by all liquids. The method of investigation was to use a powerful beam of sunlight from a heliostat concentrated by a 7″ telescope objective combined with a short focus lens. This was passed through a blue-violet filter and then through the liquid under examination contained in an evacuated bulb and purified by repeated distillation *in vacuo*. A second filter of green glass was used which was complementary in colour to the blue-violet filter. If it were placed in the track of the incident-light, all illumination disappears, while, if it be placed between the bulk and the observer's eye, the opalescent track within the liquid continued to be visible, though less brightly.

All the liquids examined (and they were some 80 in number) showed the effect in a striking manner. There was therefore no longer any doubt that the phenomenon was universal in character; with the bulb of toluene on the lantern, you see that the effect is readily demonstra-

ble. The cone of light vanishes when I place the violet and green filters together, but it appears when I transfer the latter to a place between my audience and the observation bulb.

Now the test with the complementary filters is precisely that ordinarily used for detecting fluorescence and indeed was first suggested by Stokes in his investigations on the subject. You may therefore rightly ask me the question how does this phenomenon differ from fluorescence? The answer to the question is, firstly, that it is of an entirely different order of intensity. A more satisfactory proof was however forthcoming when Mr Krishnan and myself examined the polarisation of this new type of radiation and found that it was nearly as strong as that of the ordinary light-scattering in many cases, and is thus quite distinct from ordinary fluorescence which is usually unpolarised.

This is shown for the case of toluene in Figs. 1 and 2 in Plate XII. Fig. 1 is a photograph of the scattering by toluene of sunlight filtered through a blue-violet glass. It was taken through a double-image prism of iceland spar with an exposure of 3 seconds. Fig. 2 is a picture with an additional complementary filter of green glass interposed in front of the camera lens. The exposure necessary is now increased greatly by the insensitiveness of the plate to green light, and had to be as much as 25 minutes. It will be noticed that the polarisation of the track as shown by the difference in brightness of the two polarised images is quite as prominent in Fig. 2 as in Fig. 1.

I may also mention that Mr Krishnan and myself have succeeded in detecting the new radiation and observing its partial polarisation in a number of organic vapours and also in the gases CO_2 and N_2O. The problem in these cases is one of securing sufficient intensity of scattering for the effect to be detectable through the complementary filter. This can be secured by heating up the substance in a sealed bulb or by using steel observation-vessels for containing the compressed gases, so as to obtain sufficient density of the scattering molecules. The question of the background against which the track is observed is also of great importance.

The new type of secondary radiation is also observable in crystals such as ice, and in amorphous solids. It is thus a phenomenon whose universal nature has to be recognised.

Line-spectrum of new radiation

That the secondary radiation passes the complementary filter and yet is strongly polarised to an extent comparable with the ordinary molecular scattering, is clear evidence that we have in it an entirely new type of secondary radiation which is distinct from either the ordinary scattering or the usual type of fluorescence. A striking and even startling confirmation of this view is furnished by an examination of its spectrum. Preliminary observations, with sunlight filtered through a combination which passes a narrow range of wavelengths, showed the spectrum of the new radiation to consist mainly of a narrow range of wavelengths clearly separated from the incident spectrum by a dark space. This encouraged me to take up observations with a monochromatic source of light.

A quartz mercury lamp with a filter which completely cuts out all the visible lines of longer wavelength than the indigo line 4,358A.U. was found to be very effective. When the light from such a lamp was passed through the bulb containing a dust-free liquid, and the spectrum of the scattered light was observed through a direct-vision spectroscope, it was found to exhibit two or more sharp bright lines in the blue and green regions of the spectrum. These lines are not present in the spectrum of the incident-light or in the unfiltered light of the mercury arc and are thus manufactured by the molecules of the liquid.

Figures 3(1) and 3(2), and Figs. 4(1) and 4(2) show the phenomenon. They are spectrograms taken with a small Hilger quartz instrument of the scattering by *liquid* benzene. Fig. 3 was taken with the light from the quartz mercury arc filtered through a blue glass which allows the wavelengths from about 3,500A.U. to 4,400A.U. to pass through. Fig. 3(1) represents the incident-spectrum and Fig. 3(2) the scattered-spectrum. and the latter shows a number of sharp lines not present in

Fig. 3(1). These are indicated in the figure. Figs. 4(1) and (2) similarly represent the incident and scattered spectra with benzene liquid, the filter used being a potassium permanganate solution. Here again the new lines which appear are indicated in the figure. Visual observations were also made using a quinine sulphate solution together with the blue glass as a filter and thus cutting off all the radiations except 4,358A.U. from the incident-spectrum. Some of the modified lines then disappear, leaving only those of longer wavelength. It is thus clear that each line in the incident-spectrum gives rise to at least two lines in the scattered-spectrum, one in the original or unmodified position, and a second in a shifted position of longer wavelength. There is thus a striking analogy with the Compton effect in the X-ray region. There has, as yet, not been sufficient time for photographing the spectra from a large number of liquids, or even for measuring the photographs already obtained. Visual observations have however been made with a large number of liquids. There is an astonishing similarity between the spectra obtained with different liquids. When only the 4,358 line was used, most liquids showed in the spectrum of the scattered light, a bright line in the blue-green region of the spectrum (about 5,000A.U.), whose position was practically the same for chemically similar liquids such as pentane, hexane and octane, for instance. There was, however, a recognisable difference in the position of the modified line when other liquids such as benzene or water were used. When the 4,047 line of the mercury arc was let in by removing the quinine sulphate solution, a second modified line in the blue region of the spectrum was seen with most liquids.

Photographs obtained so far with benzene and toluene suggest that there may be several modified lines, and that each modified line may be a doublet in some cases. In many liquids, the scattered-spectrum shows in addition to sharp lines an unmistakable continuous spectrum accompanying it. Carbon disulphide behaves in an exceptional manner, showing a diffuse band.

Observations already made show that the new lines in the scattered-spectrum are usually markedly polarised; they also suggest that a continuous spectrum, when present, is less markedly polarised.

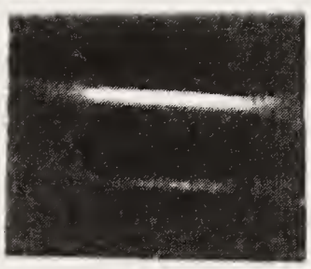


Fig. 1

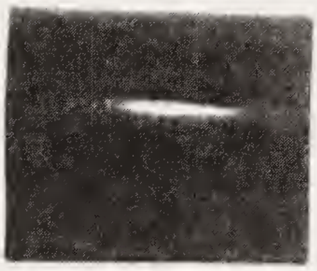


Fig. 2

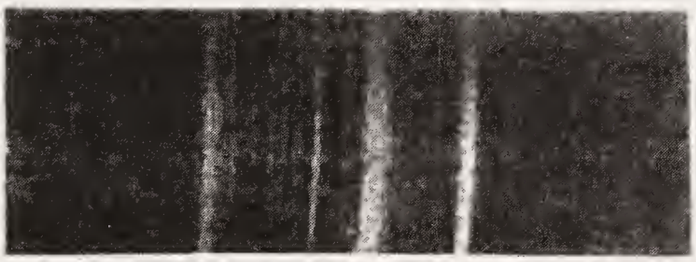


Fig. 3(1)

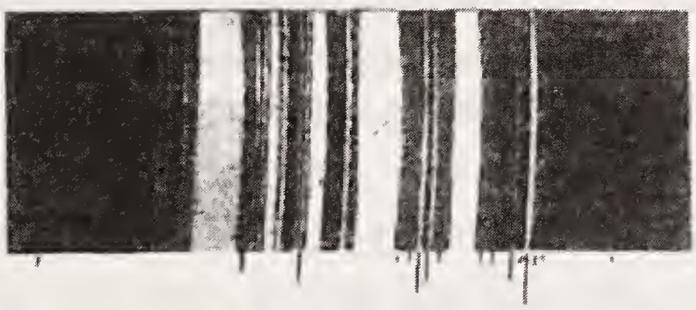


Fig. 3(2)

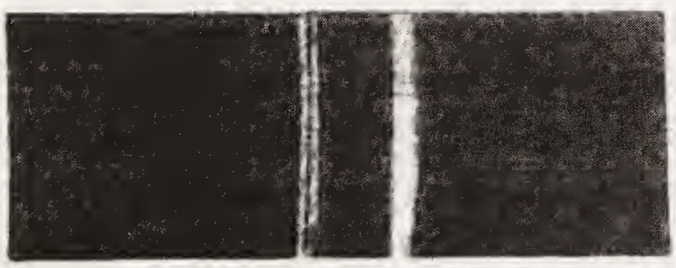


Fig. 4(1)

Fig. 4(2)

Polarisation of Scattering, Fig. 1. Unmodified; Fig. 2. Modified; Fig. 3(1). Incident Spectrum; Fig. 3(2). Scattered Spectrum; Fig. 4(1). Incident Spectrum; Fig. 4(2). Scattered Spectrum.

The first Raman spectra demonstrating the line nature of the Raman scattered radiation (see pages 228 and 229 for explanation).

Nature of the new radiation

The discovery set out above naturally opens up an array of problems for investigation. The most pressing question is, How is the modified scattered radiation, as we may call it, generated by the molecules of the liquid? As a tentative explanation, we may adopt the language of the quantum theory, and say that the incident quantum of radiation is partially absorbed by the molecule, and that the unabsorbed part is scattered. The suggestion does not seem to be altogether absurd and indeed such a possibility is already contemplated in the Kramers-Heisenberg theory of dispersion. If we accept the idea indicated above, then the difference between the incident and scattered quanta would correspond to a quantum of absorption by the molecule. The measurement of the frequencies of the new spectral lines thus opens a new pathway of research into molecular spectra, particularly those in the infra-red region.

If a molecule can take up part of the incident quantum of radiation and scatter the remaining part, then it might also be capable of adding a quantum of its own characteristic frequency to the incident-radiation when scattering it. In such a case we should expect a modified line of *increased* frequency. Such a result appears to be shown in Fig. 3(2) of Plate XII, as a solitary line in the extreme left of the photograph. This result, however, requires to be confirmed by more photographs and with other liquids. So far it would appear that a degradation of frequency is more probable than an enhancement. It is too early to speculate at present on the origin of the continuous radiation observed in some cases, whether it is due to changes in the molecule itself, or whether it arises from inelastic collisions of the second kind within the liquid, resulting in *partial* transformation of the incident quantum of radiation into translatory kinetic energy of the molecules. When further data are obtained, it should be possible to express a definite opinion of this point, and also on the role played by the solvent in the explanation of ordinary fluorescence.

Relation to thermodynamics

As explained in the introduction, the ordinary scattering of light can be regarded equally well as a molecular effect and as a bulk effect arising from the thermodynamic fluctuations of the whole medium. The question arises whether the new type of secondary radiation is exclusively a molecular effect or not, and whether it is related in any way to thermodynamics. The question is obviously one to be answered by experiment and theory conjointly. The comparative study of the effect at different temperatures and in different states of aggregation of matter is obviously of great importance in this connection. It has already been remarked that the effect is observable in gases and vapours and indeed it is found possible to determine its intensity and polarisation in the gaseous state. It is also of great interest to remark that the solid crystal ice also shows the sharp modified lines in the scattered-spectrum in approximately the same positions as pure water. The only observations made with amorphous solids are with optical glass. Here the modified scattered-spectrum consists of diffuse bands and not sharp lines. Whether this is generally true for all amorphous solids, and whether any changes occur at low and high temperatures remains to be determined by experiment.

Coherent or non-coherent radiation?

An important question to be decided in the first instance by experiment is whether the modified scattered-radiations from the different molecules are incoherent with each other. One is tempted to assume that this must be the case, but a somewhat astonishing observation made with liquid carbon dioxide contained in steel observation vessels gives us pause here. It was found on blowing off the CO_2 by opening a stop-cock, a cloud formed within the vessels which scattered light strongly in the ordinary way. On viewing the cloud through the complementary filter, the scattered-radiation of modified frequency also brightened up greatly. This would suggest that the assumption of non-coherence is unjustifiable. Further, some qualitative observations suggest that the modified scattering by a mixture of carbon disulphide

and methyl alcohol also brightens up notably at the critical solution temperature. Quantitative observations are necessary to decide the very fundamental question here raised.

Possible X-Ray analogies

If a quantum of radiation can be absorbed in part and scattered in part in the optical region of the spectrum, should not similar phenomena also occur in X-ray-scattering? The type of scattering discovered by Prof. Compton may possibly be only one of numerous other types of scattering with modified frequencies, some with a line-spectrum and some in the nature of continuous radiation. The extreme ultra-violet region of the spectrum may also furnish us with numerous examples of the new type of radiation, which clearly occupies a position intermediate between scattering and fluorescence.

Conclusion

We are obviously only at the fringe of a fascinating new region of experimental research which promises to throw light on diverse problems relating to radiation and wave-theory. X-ray optics, atomic and molecular spectra, fluorescence and scattering, thermodynamics and chemistry. It all remains to be worked out.

I have to add in conclusion that I owe much to the valuable co-operation in this research of Mr. K.S. Krishnan, and the assistance of Mr S. Venkateswaran and other workers in my laboratory.

The line-spectrum of the new radiation was first seen on February 28, 1928. The observation was given publicity the following day.

Davisson on Raman

An unusually candid account of Raman's discovery was written by C. J. Davisson of Bell Laboratories in 1931. It appeared in the *Bell Laboratories Record* just after Raman was honoured by the award of

the Nobel Prize for Physics in 1930. Five years later, Davisson himself shared a Nobel Prize in Physics with G. P. Thomson for demonstrating the wave nature of electrons. Very brief extracts from this are quoted in the beginning of this Memoir. I reproduce here the full account:

> "In awarding the Nobel Prize in Physics for 1930 to Sir C. V. Raman, the Swedish Academy concurred with physicists the world over in appraising the discovery of the "Raman Effect" as one of the most important achievements in physics in recent years.
>
> As on some previous occasions, the award this time is made, nominally at any rate, for a single experimental result of striking importance. Again as on previous occasions, the particular experiment to receive this signal recognition is a rather simple one — one which might have been made with equipment at hand in almost any physical laboratory in the world at any time during the last forty or fifty years. Indeed, within a year of Raman's announcement of his discovery, the effect was verified and studied by more than forty investigators in countries other than India.
>
> In its simplest form the experiment consists in irradiating a transparent substance with monochromatic light, and observing the spectrum of the light which the substance scatters. Raman found that the scattered-light comprises, in addition to a line of the same wavelength as the incident radiation, a few much fainter lines as well, which additional lines are in a sense satellites of the primary line, moving with it as a group through the spectrum when the wavelength of the primary radiation is altered.
>
> In the first definitive experiment of this kind, Raman photographed the spectra of the radiation scattered by various organic compounds when illuminated by a part of the spectrum of a mercury arc. On long exposure the plates revealed these additional or secondary lines not present in the primary light. It was found possible to classify these secondary lines into groups each associated with a single one of the primary lines; corresponding members of the various groups are dis-

placed in frequency each by the same amount from its primary. The different groups may overlap in the spectrum, making the sorting out difficult but not impossible. A group may extend on both sides of the primary; as a rule, more and stronger lines are found on the side of lower frequencies. Such lines as do appear on the high frequency side are found always to be matched by lines of equal displacement on the low frequency side. It is as if the scattering material has at its disposal a small collection of frequencies which it can add to that of the incident-light or subtract from it, and as if it prefers subtraction to addition. These simple numerical relationships distinguish the Raman Effect from the somewhat similar phenomenon of fluorescence — these and the fact that the Raman Effect appears to be a universal phenomenon observable with any transparent medium, gaseous, liquid or solid, whereas fluorescence is exhibited by a limited class of materials only.

The simple numerical relationships which have been mentioned as characteristic of the Raman Effect, and one other which is to be described further on, are easily explained in terms of light quanta and the known properties of molecules. This is one of the reasons for regarding the discovery of the Raman Effect as an event of great importance; it makes an addition to the list of phenomena which are conveniently interpreted by regarding light as a corpuscular as well as a wave phenomenon.

Since Einstein in 1906 rehabilitated the corpuscular theory of light to explain the photoelectric effect, and more especially since the discovery of the Compton effect in 1924, it has become steadily more imperative to recognise that light has these two apparently irreconcilable aspects; a beam of light is a flight of particles or a propagation of trains of waves, depending upon the particular phenomenon which is to be explained or visualised. In explaining some phenomena it is even necessary, or at least convenient, to oscillate between the two views at different stages of the argument. In such cases, translation from one to the other is made by means of two well-established laws: the energy of the light particles or photons is strictly proportional to

the frequency (waves per second) of the associated undulations, and similarly the momentum of the photons is strictly proportional to the wave number (waves per centimetre) of the undulations. The factor of proportionality is in both cases the so-called Planck constant h.

In the corpuscular explanation, the Raman Effect is due to interchanges of energy occurring in encounters between photons of the incident light and molecules of the scattering material. Photons emerge from these encounters with altered energy; they constitute the scattered-light of altered frequency and altered wavelength which Raman detected. Now every kind of molecule or atom has the following peculiar property; its internal energy is limited to certain definite discrete values. The molecule is capable of existence only at certain 'energy levels', and can accept or give up energy only in amounts which will raise or lower it, from the particular level in which it happens to be to another of its levels.

Thus the photons may give up to the molecules only one or another of these characteristic amounts of energy, and, in consequence of the direct proportionality between energy and frequency, the frequency of the associated waves should be lowered only by corresponding amounts. It is for this reason that the Raman spectrum is a spectrum of sharp lines. The frequency displacements in the Raman spectrum should correspond to differences between energy levels of the molecules; and in cases in which these latter are already known, this relationship is verified.

The Raman lines on the high frequency side of the primary line may be explained on the general principle that processes of the kind mentioned in the last paragraph are necessarily reversible. If it is possible for a photon to give up a part of its energy in raising a molecule from one level to another, it must be possible also for the molecule in passing in the opposite direction to impart an equal amount of energy to a colliding photon. This process is the analogue of what is known in encounters between electrons and atoms as a 'collision of the second kind'. The presence of high-frequency components in the Raman spectrum symmetrical with the low-frequency components is due to

such encounters. These components are weaker than their companions because at ordinary temperatures nearly all of the molecules are in their state of lowest energy and are incapable therefore of imparting energy.

Thus, the importance of Raman's discovery is due partly to its revealing a previously unknown process in nature, partly to the additional basis of reality which it affords to the photon, and partly to its supplying a new and convenient method of investigating the energy level of molecules.

It was remarked earlier on that the Raman experiment is a rather simple one which might have been made with equipment available in any physical laboratory at any time in recent decades. It was no accident, however, that this particular discovery was made by Raman rather than by someone else. Important discoveries in physics, even quite simple ones, are usually made only by investigators who have cultivated intensively the particular field concerned, and this is strikingly true in the present instance. No one else in recent years has been as assiduous in the study of the scattering of light as Professor Raman. True, in the years just following his graduation from Presidency College, Madras, in 1907, his interest — if we may judge from his publications — centred chiefly in the vibrations of mechanical systems — stringed musical instruments in particular — and other acoustical problems. But even in these years problems in optics claimed a part of his attention. About 1920, however — three years after he became Sir Taraknath Palit Professor of Physics at Calcutta University — he turned abruptly from studies in acoustics and devoted himself almost exclusively to optics and particularly to investigations of scattering, both theoretical and experimental. Of one hundred papers and notes published by Raman independently, or in collaboration with his associates and students, since that time, eighty-three deal with problems in optics and forty-nine of these with the scattering of light.

It speaks well for the development of Science in India that Professor Raman apparently owes little or nothing of his eminence to direct contact with physicists in other countries. His formal training was re-

ceived entirely in India, and, except for a single year, he has worked only in his native land. In 1924 he attended the Toronto meeting of the British Association and afterwards carried on his researches for some months at California Institute of Technology.

His previous honours, which have been numerous, include the general presidency of the Indian Science Congress and fellowship in the Royal Society. Knighthood was conferred upon him by King George in 1929. India may well be proud of Sir Chandrasekhara Venkata Raman, her first Nobel Laureate in Science."

Epilogue

Raman's life has been an extraordinary one in many ways. But his most significant act in that extraordinary life was that he took to the pursuit of Science, against all conventional wisdom prevalent in his time. What prompted him to do so is obvious in hindsight. He had an irresistible passion for physics, and the creative spirit in him drove him to seek the opportunity to make his dreams in that discipline come true. However, the destiny of an individual is the result of interaction between his free will and external circumstances. The latter are more often opportunities that come by chance, over which the individual has no control. In almost every person's life these elements play an important role. In Raman's life, his entry into Government Service gave him the financial independence to pursue his interest in physics and his posting to Calcutta gave him the unique opportunity of discovering a scientific institution suited to his temperament.

At that time, Calcutta had the best intellectual and cultural traditions in India. Science had taken root there as an important intellectual pursuit. On this, Raman has said:

> "Whether a great populous city offers the most suitable environment for the pursuit of scientific research may well be questioned. Many instances may be cited which seem unfavourable to the supposition. That the centre of gravity of Science in Great Britain is to be found at Cambridge and not in London or Edinburgh is probably no accident. But Paris is a typical example of a great city which is not only the political and social but also the intellectual capital of its country.

> Calcutta claims a similar privilege so far as Bengal is concerned, but an impartial observer would probably also conclude without hesitation that the proud privilege she once enjoyed of being the Imperial Capital has not yet disappeared in the sphere of scientific activity. She owes her prestige and influence in the sphere of learning to her centuries old tradition of culture and research, to the long line of eminent scholars, both Indian and European, whom Calcutta had and has in numbers among her citizens, and not least to the efforts of such men as the late Dr Mahendra Lal Sircar and Sir Asutosh Mookerjee, who strove to create the facilities for higher studies and research that others now enjoy".

But for this intellectual atmosphere, there would not have been an Indian Association for the Cultivation of Science to provide Raman with an opportunity to renew his interest in physics. Raman's discovery of the existence of the Association was accidental. The open arms with which he was welcomed into it were the encouragement he needed. Both were important turning points in his life. Further, the Association was just the right body for Raman's personality, because he functioned at his best when he had all the independence and freedom to act and make the decisions.

Raman possessed an indomitable spirit and an abiding love of Science. He demonstrated by his example that independent thinking, hard work, self-confidence and utter dedication are absolute necessities for scientific achievement. Raman's scientific intuition guided him to choose important problems that could be tackled with the meagre facilities available and he made a mark in whatever area he chose to investigate with these facilities. From 1907 to 1917 Raman worked very hard, for his official work, as Assistant Accountant General, was considerable; he could carry out his scientific studies at the Indian Association for the Cultivation of Science only during his spare time. Yet he energetically built up laboratory facilities there, conducted experiments, and published papers.

The success of his research programmes in acoustics and optics fuelled his enthusiasm and confidence so much that, in ten years,

confident of further scientific successes, he was ready to give up his lucrative position in the Financial Civil Service. With his appointment to the Palit Professorship, Raman's transformation to a full-time scientific Life became complete.

Realising that research in optics and light scattering was the area in which great discoveries could be made, he switched from acoustics, although his successes in the latter field were spectacular. Of this he wrote in 1968: "My studies on bowed string instruments represent a phase of my earliest activities as a man of Science. They were mostly carried out between the years 1914 and 1918. My call to the professorship at the Calcutta University in July 1917 and the intensification of my interest in optics inevitably called a halt to my further studies of the violin family instruments." This was again a turning point in his scientific interest.

His innate aesthetic approach to Science, and his acceptance of the older Lord Rayleigh as his model, led him to light-scattering experiments. These he assiduously conducted with his collaborators for eight years. With perseverance, critical evaluation, and step-by-step improvements in the methods of study, he made a profound discovery that brought him a lasting reputation as a great scientist. What is amazing is that Raman became an experimentalist *par excellence*, although he had received very little training in college. Even today, the training in Indian universities tends to be more theoretically oriented. It was more so during Raman's time.

The scientific spirit is manifested primarily as a curiosity about Nature and a deep desire to understand natural phenomena. Experimentation, observation and interpretation constitute the methodology of Science. Perseverance and dedication are its operational requirements. By his life and work, Raman showed how a true scientist should think, function and act. Never for a moment did he lose his interest in Science, despite the disappointments and frustrations he had to face in his lifetime.

Raman did not have any false modesty. In fact, he was a supreme egotist, who was susceptible to flattery. At times he exhibited uncontrollable anger and was even very rude in his remarks. He was often

criticised for these shortcomings. But to persons who knew him well, his qualities as a great scientist and lover of Nature overshadowed these shortcomings. His enthusiasm, his simplicity and his directness touched anyone who came near him.

Some important dates in the life of C. V. Raman

1888, November 7	—	Born at Thiruvanaikkaval near Tiruchchirappalli
1892–1902	—	Early education at Visakhapatnam
1900	—	Matriculation Examination
1902	—	F.A. Examination, joins Presidency College, Madras
1904	—	B.A., 1st Rank, Gold Medal
1906	—	First paper published in *Philos. Mag.*, London
1907	—	M.A.; Financial Civil Service Examination, 1st Rank
	—	Married Lokasundari
	—	Posted as Assistant Accountant-General, Indian Finance Department, Calcutta
	—	Starts working at the Indian Association for the Cultivation of Science (IACS), Calcutta
1907–1917	—	Officer, Finance Department, at Calcutta, Rangoon, Nagpur, Calcutta
1917, July	—	Palit Professor of Physics, Calcutta University
1919, November	—	Secretary, IACS
1921	—	First visit abroad (to England)
1924	—	Elected Fellow of the Royal Society, London
1928, February 28	—	Discovery of the Raman Effect in Calcutta at the IACS

1928, March 16	—	First public lecture on the Raman Effect before the South Indian Science Association at Central College, Bangalore
1929	—	Knighthood of the British Government
1930	—	Nobel Prize for Physics
	—	Hughes Medal of the Royal Society
1933, March 31	—	Director, Indian Institute of Science, Bangalore
1934	—	Indian Academy of Sciences started by Raman
1935–36	—	Raman–Nath Theory: Diffraction of light by ultrasonic waves
1937	—	Resigns from the Directorship of IISc, but continues as Professor and Head, Department of Physics
1940	—	Raman–Nedungadi discovery of the soft mode behaviour in quartz
1942	—	Franklin Medal
1948, July	—	Retires from IISc.
	—	Raman Research Institute established
	—	Appointed National Research Professor
1954	—	Bharat Ratna
1957	—	International Lenin Peace Prize of the Soviet Union
1961	—	Member, Pontifical Academy of Sciences, The Vatican
1970, November 21	—	Passes away in Bangalore

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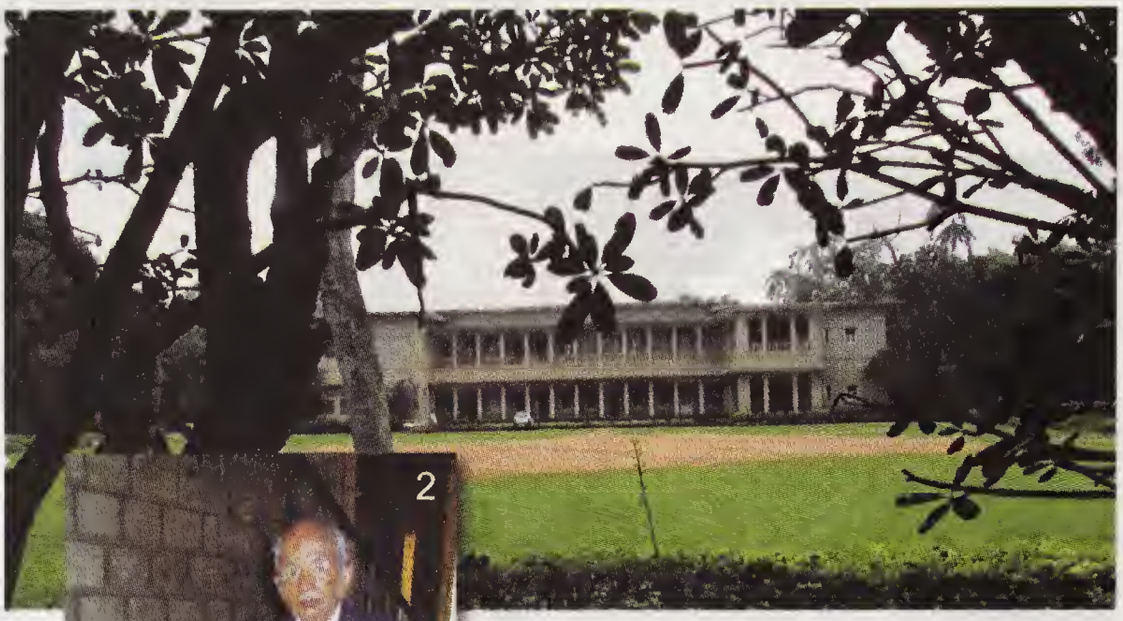
(22)

Bangalore is in many ways an
ideal location for the establishment of
a new foundation for scientific
research in India. Its situation on
three thousand
~~Sixty~~ feet above sea level on the
Mysore plateau endows it with one
of the most agreeable climates to be
found anywhere in the world. This
fact and the amenities provided
for the city by an enlightened
administration have contributed
to its rapid growth as a centre
of education, research and
industry. Kempe Gowda of

1. C.V. Raman
2. Commemorative stamp released by the Indian Postal Department in 1971.
3. A page from Raman's diary.



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1. Raman Research Institute main complex.
2. The author visiting the institute in 2016.
3. A display of minerals at the Raman Research Institute Museum.

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Dr Jayaraman is the recipient of Krishnan Gold Medal of the Indian Geophysical Union (1968), The Guggenheim Award from The John Simon Guggenheim Foundation, New York (1969), The Humboldt Senior US Scientist Award (1979) to do research at the Max Planck Institute in Stuttgart, Germany, Distinguished Scientist Award from Bell Labs in 1983, and the Raman Centenary Medal (1988). He is a Fellow of the Indian Academy of Sciences and the American Physical Society.

Back Cover

Top: A specimen of Labradorite

Bottom: The tree *Tabebuia donnell-smithii* marks the spot where Raman was cremated on the lawns of RRI

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Subhankar Biswas